Automatic Surveying Instruments and their Practical Uses on Land and Water

BY

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WITH AN INTRODUCTION

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PREFACE.

BEFORE proceeding to the customary "apology" for having saddled this book-ridden age with another production, I may be allowed to direct attention to the solid moral support lent both to the title-page and the contents of this booklet by the author of its introductory lines. To say that I am indebted to Professor Hammer would be putting it mild, seeing that I am not sure whether, without that gentleman's encouragement and contributed chapter, I should have found the hardihood of attempting to foist what is virtually a new chapter upon a science (some call it art) as old as the world.

From the time when I first became interested in automatic surveying instruments I have missed no opportunity of tracing whatever information I could lay hold of concerning similar or kindred devices, all of which, however, led to little or no result. Some tangible information was tracked home to the various patent-office records, a few descriptions of instruments of that kind being found there which, however, proved to be mostly so complicated, or bore such evident marks of never having passed beyond the experimenting stage, if indeed they ever got so far, that I should not have felt justified in embodying a description of any of them in this book. Being, moreover, unable

to find mention of automatic "route-tracers" in any text-book on topography, even in such as specialise on the subject of *instruments*, I could not but reach the conclusion that the subject—in its practical aspect, at any rate—is really new, and that the instruments treated of in this little volume really represent all that —with the best possible of intentions—I can offer in satisfaction of the scope covered by its title.

Another point calling for a few comments is what led me into writing this book at all. Such was certainly not my original intention, and it only became so when I had realised that the subject had outgrown the dimensions of the average article in a technical journal; a perusal of a short description in matters like these, where everything depends upon small practical details, leaving the reader much where he was before. It was with the object, therefore, of bringing together *all* information of practical value concerning these instruments into a shape both handy for reference and fairly exhaustive as regards details, that I decided upon this course. The subject as it is—quite apart from the question whether these pages do or do not contain the right solution—must be pregnant of great interest to many among the most varied professions and occupations scattered all over the globe. These will here find a few practically tested solutions, treated with more detailed information than they could have obtained from a perusal of a fairly long list of periodical articles, appeared on the subject, which I shall therefore not enumerate here. Nor does this book seem to be the place for a restatement of professional opinions, testimonials, outcome of official trials, &c., concerning some of the devices treated of,

the whole object being merely to present the matter in such a shape as to enable those interested to form opinions entirely their own on the subject. If, besides, there may be found occasional points of more general interest regarding theoretical difficulties surmounted, practical "dodges" applied, &c., useful in other respects or suggesting other ideas, the main object of this book will have been amply attained and no further need of "apology" apprehended by its author.

In conclusion, I should record my indebtedness to Captain W. Ferd. Tyler, China Coast Inspector, for the original suggestion of an automatic "dead reckoner," the hodograph being, in fact, a practical evolution of various ideas offered by me for simplifying the execution of an original design by that gentleman, who was prevented from going any further into the matter by want of leisure. I am also under many obligations to Mr. N. G. van Huffel, Ph.D. manager of the "Nederlandsche Instrumentenfabriek" at Utrecht, whose enterprise in manufacturing the pedograph from the outset in sufficiently large quantities to enable due attention to be given to the smallest details of construction, was instrumental in obtaining several of those final improvements, which may mean all the difference between success and failure. The preliminary model work subsequently required for the cyclograph was attended to, free, by the same factory. Some useful details of construction in the pedograph also trace their origin to suggestions received from Mr. J. H. Steward, of the well-known house of that name in London.

In writing this book I have made free use of the contents of two papers, read before the Shanghai

Society of Engineers and Architects on parts of the subject, while chap. iii. is practically a translation of an article by myself in *De Ingenieur*, the weekly journal of the Royal Netherlands Institution of Engineers.

THOS. FERGUSON.

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INTRODUCTION.

By E. Hammer, Ph.D., *Professor of Geodesy at the Royal Technical High School of Stuttgart.*

Instruments for automatically tracing a plan of a road over which they are transported, or for automatically arriving at the longitudinal section (levelling) of the line over which they are carried, have been repeatedly constructed or sketched. As to those of the latter kind, I shall merely mention that of de Villepigue. All of these instruments, however, have failed to attain any importance in surveying practice of minor accuracy, partly because they are too complicated, and therefore too expensive and apt to get out of order; partly from other causes.

A few years ago, Mr. Thomas Ferguson, the author of the present little volume, has joined this series of inventors with his Hodograph, which was soon followed by the Pedograph, and recently by the Cyclograph: instruments for automatically tracing the *plan* of itineraries performed on water (*Hodograph*) or on land (by the pedestrian: *Pedograph;* by vehicle on wheels, more especially the bicycle: *Cyclograph*); simple and cheap instruments giving an accuracy adequate for many purposes, and therefore worthy of extended application. Especially the Pedograph

and the Cyclograph will henceforth not fail to find a place in many surveying operations.

The earlier descriptions of these instruments by the inventor, having made their appearance in journals hardly obtainable in Europe (Proceedings of the Shanghai Society of Engineers and Architects) or little known outside the country of their publication (*De Ingenieur, &c.*), and having myself drawn the attention of German readers to these instruments by reviews in some German periodicals (*Zeitschrift für Instrumentenkunde, Berlin; Petermann's Geographische Mitteilungen, Gotha; Geographisches Jahrbuch, Gotha*), I have encouraged Mr. Ferguson in his idea of publishing a complete little work on these instruments and at his request, gladly consented to preface his book with a few introductory remarks. I do not propose here to treat either of the construction of the three instruments, or of the tests they have undergone up to date, or the accuracy of the surveys produced by them, all these matters being the object of the following pages, but propose to add only a few remarks connected with these points, and concerning the scope of application which the instruments in question may be allowed to cover.

First of all I have to insist upon the instruments not being intended for *precise* surveying. They are, in fact, what may be styled *interpolating instruments*, *i.e.*, devices by which an itinerary of not too great a length and determined by its two extremities, may be interpolated between those two points, which must either be already plotted on the map, plan or chart, or given by their geodetic or geographical co-ordinates; or the control of the instrumental automatic survey

may be obtained by closing the circuit of traverse in itself, viz.: bringing together the two terminal points, in this case the points of departure and of return.

Nevertheless there are a great number of military, civil and scientific purposes for which the accuracy obtainable by the Pedograph and the Cyclograph is sufficient. For some such purposes, moreover, it must surely be of great value that the automatic record of the traversed road or line can be obtained in the dark of night, in fog, or during a march through high grass, bush or woodland (impeding the view) with no more labour or difficulty than at other times or elsewhere, at least with regard to the line of traverse itself.

I have no doubt that for *military sketches or reconnaissances* the Pedograph and the Cyclograph will in future be found a means of greatly adding both to the speed and facility of such work, as well as to the choice of *personnel* employed in it. It was a good plan to supplement the pacing instrument, the Pedograph, by a wheeling instrument, the Cyclograph, which is less affected by inclinations of the line of traverse. Wherever a vehicle with this instrument attached to it may be employed, or wherever a bicycle can be trundled by its dismounted rider, the Cyclograph will give the distances and therefore the plan fairly correctly, while in the use of the Pedograph by a pedestrian with little experience in pacing over sloping ground, a light slope or little declivities on the traversed line will soon prove to be a source of loss to the accuracy of the record drawn. Besides, the speed of a survey by the aid of the former instrument is of course still greater than by using the latter.

For automatically surveying *routes and itineraries*

on land and water, the instruments will be appreciated as a great facility to the traveller. The simplicity of their manipulation (with the Pedograph, for instance, only a compass-needle and a rough level on the top of the box need be observed during the march, which can be done as well by a porter without any knowledge of surveying, surveying instruments, or the uses of a survey) will enable many Europeans, *missionaries, planters, &c.*, in the Colonies or other countries beyond the seas, to obtain surveys which they would not have been able to perform with the ordinary surveying instruments, in the handling of which they are not used.

I may therefore express the hope that the author of this contribution to practical topography may see his persevering inventor's labours rewarded by an extensive application of his clever devices. These instruments will, I would repeat in conclusion, prove very useful in some branches of such chapters of practical geography as are comprised by me within the term "Geographic Surveying."

E. HAMMER.

Stuttgart, November, 1903.

Automatic Surveying Instruments, and their Practical Uses on Land and Water.

CHAPTER I.

THE PEDOGRAPH, AN AUTOMATIC ROUTE-TRACER FOR PEDESTRIANS.

UNDERLYING PRINCIPLE.

IT is natural, seeing how large a portion of the less rigorous topographical work, as well as practically all military sketching and reconnaissance, depends on the human pace as an unit of land measure, that in casting about for a handy route-tracing device of the widest possible range of applicability, early thoughts should revert to *pacing* as the most suitable basis, whatever in other respects its shortcomings may amount to. The pedograph is the outcome of endeavours in this direction, and though in a later instrument described hereafter, the author has, in deference to the higher requirements of particular cases, abandoned pacing for the more accurate mode of measuring distance by wheel-revolutions, the self-evident complications engendered by the latter system are not without their restricting influence upon its scope of applicability. The pedograph may therefore be held to be the more widely useful instrument of the two. Shortly defined,

it might be described as a semi-automatic instrument, designed for drawing a plan of the path followed by a pedestrian, in which the distances made good by the latter are automatically plotted to scale on paper through a mechanical action depending on the number of paces taken, while at the same time the operator is enabled by means of a very simple manipulation, after the indications of an attached compass-needle, to cause such plotted distances to fall automatically in the various directions and curves corresponding to those on the road actually followed in nature. The pedograph therefore gives its record immediately in chart-form as quickly as one can walk over the route. Before proceeding to a detailed description of its construction, &c., a few remarks as to the unit upon which all its registered distances depend, seem to be called for here.

The Use of Pacing in Topography.

As already stated, the pedograph depends entirely upon *pacing* for its distances, and this fact being decidedly its weakest point, the pertinent question arises in how far pacing may be employed in topography, and where exactly one should look for the limitations of this mode of measurement. While it might in passing be pointed out that almost all military sketching depends on paced distances, the main question here involves the broader issue of topography in general, of which military sketching forms only a part, though certainly important enough a part as far as the pedograph is concerned. Now there has always been among surveying men a great diversity of opinion

regarding the use and reliability of pacing in general. Much of this difference, of course, arises through the variety of ways in which the paces are counted and reduced to land measure, the various purposes for which and conditions under which the method is applied, and the varying amount of skill and judgment exercised in embodying the results. Some have used, and after a while probably condemned the *pedometer*, a little device in which a pointer indicates in *miles* on a dial and in which the presence of an adjusting screw lures one into the totally erroneous idea that the instrument might be adjusted to the individual length of step, which factor is needed for the conversion of paces into miles. A more honest instrument is the *passometer*, which confines itself to indicating the *number of paces* taken, leaving it to each operator to apply his own personal reduction. This would be quite satisfactory, were it not that in these small watch-like contrivances the oscillating hammer has to be very delicately poised and so light that it is likely to rebound and register an extra pace for a somewhat jarring step. With one of these instruments the author has found it possible to assume a certain gait at which the instrument registers two paces for every single step taken. Such vagaries have earned for both pedometer and passometer the reputation of being quite unreliable, and it is probably for that reason that some topographers will have nothing to do with either, but insist on *counting* their paces. This system, however, is subject to personal mistakes, while it also engrosses all the attention of the observer and prevents him thinking out a matter as he walks, or making the little mental calculations so often occurring in the field. In

the pedograph the mechanism for registering distances resembles that of the passometer, hence the distances marked are direct functions of *number of paces*, while in the construction of the oscillating hammer, which is much heavier than that of a pedometer, various precautions have been taken to reduce the chances of false rebounds to a minimum.

Another phase of the matter, also subject to much difference of opinion, is the question in how far the paces themselves may be considered a stable unit, granting that they have been accurately counted. While a great deal depends on the nature of the ground, the degree of accuracy called for, the frequency of independent control and the judgment with which the results are embodied, it is certain that excellent results on a large scale have on many occasions been attained, and that for ordinary reconnaissances in level or moderately undulating countries the applicability of pacing methods is beyond cavil. In this connection we may give due weight to the opinion of Mr. H. M. Wilson, United States Geographer, who, in his valuable work on "Topographic Surveying" (J. Wiley, New York, 1901), writes as follows :—

Excellent results have been obtained in rough geographic surveys by using instrumental measurements over portions of the country, and running checked cross-lines between by *pacing*. Numbers of such lines which the writer has had run and plotted checked out in distances of 10 or 15 miles between fixed points within $\frac{1}{8}$ or $\frac{1}{10}$ of a mile, equivalent on a two-mile scale to $\frac{1}{16}$ or $\frac{1}{20}$ of an inch. Such results have not only been obtained once, but day after day for years, and by different men, in the course of rough surveys over rugged mountains and deep gorges, through brush and fallen timber.

Without necessarily implying a fully advantageous

use of the pedograph "through brush and fallen timber," the above opinion should go far to forestall a hasty disparagement of pacing methods *per se*, especially on sloping ground, where—providing it does not become actual hill-climbing—with some of the judgment and precautions doubtlessly implied in the above passage, the most useful results can still be obtained.

As to the actual length of pace, it is generally assumed that in regular pacing, results may be relied upon within 2 or 3 per cent.; but in the actual work in which the pedograph is likely to be used, it will be rarely necessary to rely upon the absolute value of the scale; all that is required being the knowledge that the scale is sufficiently *uniform* throughout. In his two years' experience in mapping with the aid of the hodograph (see chapter iii.), the author gradually drifted into the habit of not even ascertaining the exact scale on which his day's trip was drawn, all endeavours being merely directed towards keeping the scale uniform, after which the resulting trace of the route was fitted between the independently located positions of its extremities on the general map. This should also be done with pedograph surveys, it being almost always possible to obtain the required amount of independent control. Supposing then the scale to be out by a considerable amount, for instance, through an erroneous assumption that one makes 2,000 paces to the mile, whereas one really does 2,500, the situation of intermediate points would not be in the least affected by such a discrepancy. This would only be the case if some parts of the route were placed differently to others. If further precaution has been taken to fix a few additional points on the route itself by bearings

to known landmarks, the errors in position due to reasonably irregular pacing diminish so rapidly as to soon cease to be of any account. It is thus that one should render innocuous the adverse influence of bad pieces in the route, ploughed fields, steep inclines, &c.

FIG. 1.

CONSTRUCTION AND WORKING OF THE PEDOGRAPH.

Drawing-board and Ground Glass.—Fig. 1 is a reproduced photo of the pedograph, in which the

loose lid has been removed and the ground glass (see below) replaced by a pane of transparent glass. Fig. 2 is a drawing of the instrument under similar

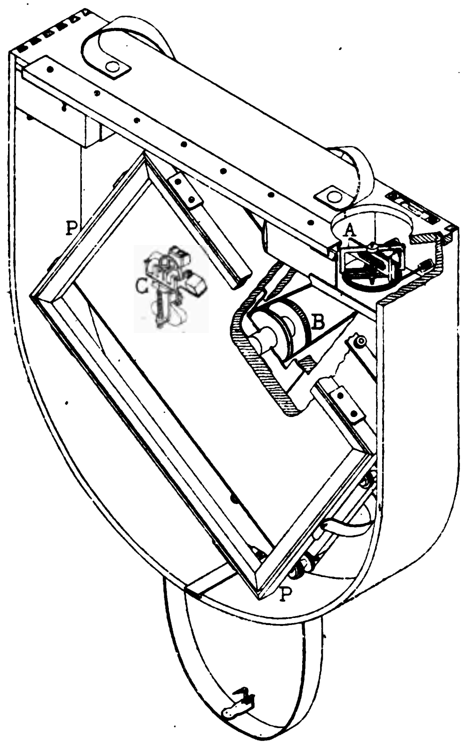


FIG. 2.

conditions, but with parts shown as cut away to expose details of construction. The whole contrivance is contained in a flat box,[1] about 12 by 12 by

[1] Normally constructed of polished wood, but for use in moist tropical climates a special style of the instrument is executed in a light aluminium-alloy.

$2\frac{1}{2}$ inches, rounded off below, which, in use, is carried suspended by means of a leather sling. A circular hole cut in the upper face of the box allows the compass (A, fig. 2), of which more below, to be duly watched. The space within the case is mainly taken up by a rectangular drawing-board, shown in fig. 1 with a sheet of paper clamped over it, and a plate of ground glass mounted in a wooden frame (P, in fig. 2) which keeps the glass exactly parallel to the drawing-board and at a distance of about 1 inch from the latter. The frame is mounted on hinges, so that the ground glass can be folded back, giving free access to the drawing-board, or closed down firmly against two screw-headed pillars by means of the curved brass spring visible in fig 2. Both these pillars and the hinges opposite are adjustable in height, which allows of true parallelism and the right distance between glass and drawing-board to be adjusted for if necessary. The drawing-board is furnished on its rear surface with a stub-axle, mounted perpendicularly upon the centre and projecting through the outer wall of the case, where it terminates in a knob (B, fig. 2). By turning this knob, the board can be revolved into any position within the box. It is in the space between drawing-board and ground glass that the separate little contrivance which does the recording is sustained and moves.

The Recorder.—The recorder (fig. 3) rests against the drawing-paper with a little steel wheel (*A*) with sharp teeth—"marking wheel"—and a smooth roller (*i*) some way below it. When the ground glass is closed into its parallel position, it catches two smooth rollers

(*h*), disposed laterally with respect to the line joining the above mentioned points of support against the drawing-paper and, with some compression of the U-shaped frame, fixes the recorder rigidly between paper and glass. The recorder is then held by four points—the minimum number to suffice—and it will be readily seen that the place of contact of the sharp

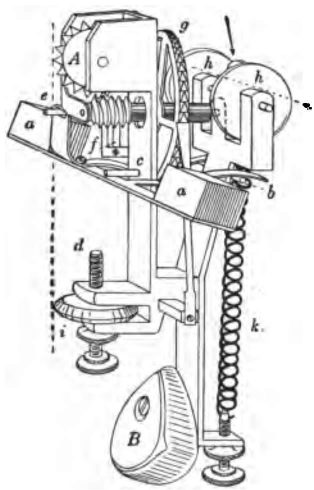


FIG. 3.

teeth (*A*) receives the greatest pressure; almost twice as much as the lateral rollers (*h*), and about ten times as much as the roller (*i*) below. But though the recorder is now held in a fixed position with respect to the parallel surfaces regarded as indefinite planes, it is still capable of movement between the surfaces; *i.e.*, as long as the marking wheel is free to revolve, the whole

concern can slide bodily into the direction in which that wheel would then run over the paper, but as soon as this revolution is arrested, there only remains a pivoting action possible round the point of contact of the sharp teeth on the paper as a fixed fulcrum for the time being, for which the three smooth rollers are all axially disposed. This pivoting action is to allow the recorder through its heavy tail-piece (*B*) to remain hanging vertically between the surfaces, while its bodily progression constitutes the actual marking on the paper. To control the rate and extent of this motion, the teeth of the marking wheel mesh into a low-pitched worm-screw forming part of the axle of a ratchet wheel (*g*). A stirrup-shaped lever, carrying two leaden bulbs (*a*) on a cross-bar at its end, is pivoted at *b* in the frame of the recorder and held in equipoise by a long spiral spring (*k*), acting on a very short projection of the lever behind the pivot. This combination of a long spring working on a short arm, ensures a highly desirable uniformity of tension throughout the hammer's swing. When the instrument is carried about in a walk, the equipoise of the hammer is disturbed and the latter then oscillates between its set limits, of which the upper one (*c*) is a fixed pin and the lower one a screw (*d*) with milled head and lock-nut, adjustable through a very wide range. Being provided with a little slotted plate into which locks a projecting pin (*e*) on a pall (*f*), working on the teeth of the above mentioned ratchet-wheel, the oscillation of the hammer brings about a step-by-step progression of that wheel, which can be made to take place by *one*, *two*, *three*, *four*, or *five* teeth at a time. This wide range has been attained by mounting the

ratchet-pall on the axle of the wheel itself, so that it always bears in the same manner on the teeth at the circumference, no matter how wide the angle. The pin-and-slot action ensures a smooth transmission of the tangential motion of the hammer into a circular one of the pall.

Scale.—Thus we have it that the rate of progression of the marking-wheel over the paper is directly controlled by the frequency of oscillation of the hammer *i.e.*, number of paces taken ; a variable link in this connection being the number of teeth moved on by each oscillation. Should this be *one* tooth—there being *fifty* in the ratchet-wheel—fifty pulsations of the hammer will bring about one revolution in that wheel, which means the progression of the marking-wheel over the paper to the extent of one tooth. Since the dots thus pricked in the paper are spaced $\frac{1}{20}$ inch apart, 1,000 paces will measure out one inch on the paper and, assuming a personal average of 2,000 paces to the mile, the scale represented will be *two inches to the mile.* If the lower stop of the hammer is withdrawn to such an extent as to allow *two* teeth to be caught for each step, the scale will be doubled; similarly, *three, four, five teeth*, will represent *six, eight, ten inches to the mile* respectively. The operator whose length of pace does not conform to the above average, has to correct the scale accordingly ; thus, supposing him to take 2,100 paces to the mile instead of 2,000, or 5 per cent. *more*, his scale comes out 5 per cent. *too large ;* he therefore works at 2·1, 4·2, 6·3, &c., inches to the mile.

Some recorders are constructed for adjustment to

the scales $\frac{1}{50000}$, $\frac{1}{25000}$, $\frac{1}{16667}$, $\frac{1}{12500}$, and $\frac{1}{10000}$. The average pace assumed in this case is 1,300 to the kilometer ; the ratchet-wheel having 65 teeth and the spur-wheel marking millimeter-dots on the paper.

The instrument does not afford, or profess to afford, the means of adjusting to personal length of pace ; this idea having been abandoned by the author under the conviction that its realisation with any approach to trustworthiness in such a light and delicately poised mechanism is impossible. An error in allowing for length of pace will only affect the scale of the record without in any way distorting its shape.

Directions.—As we have already seen, the drawing-board is pivoted on a short horizontal axis, round which it can be revolved with the ground glass into any position within the flat box containing the whole apparatus. But the recorder is also designed to retain a vertical position between the board and the glass, so that it will always follow a plumb-line in descending, no matter how the boards are placed. We have therefore a simple means of making the recorder depict on the paper a bend or corner in the road, which is merely to revolve the drawing-board through a similar angle in opposite direction. The recorder being pivoted on the marking point itself, a mere revolution in the board will not affect the drawing, but any further descent of the recorder will take place in the new direction. To enable the operator to keep always setting the drawing-board in accordance with the meanderings of the road, the axle of the board is furnished with a grooved pulley (fig. 2) round which a cord is carried transferring any revolution of this

pulley to another one of exactly equal circumference pivoted on a vertical axis immediately below the compass in the upper corner of the box. The latter pulley (C, fig. 4), has a brass frame (A) mounted on it in which is pivoted the compass-device, consisting of two magnetised needles connected by a light wooden cross-bar, through which the perpendicular pivot, pointed at both ends, is screwed. Two light spiral springs (B) can be made to slide along the length of the needles, affording the necessary means of

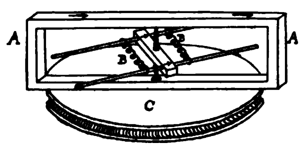


FIG. 4.

"balancing" the needle, as explained below. In a later pattern of compass a longitudinal strip of aluminium has been added midway between the needles in order to assist the eye when, as has to be done throughout the course of a walk, it is necessary to *place the brass frame parallel to the needles,* the arrow-points on frame and needles all pointing the same way. The recorder then does the rest, which is evident from the following: Supposing the operator to be walking straight to the (magnetic) north, the needles will point straight ahead, and so will the frame when brought parallel to them. Now let the path take a sharp curve to the *right;* while turning round the bend, the operator will see the needles deflect to the

left, and it will be then his business to make the frame follow suit, and so doing, he turns the drawing-board through an equal angle to the *left*. The recorder, however, is not affected by this shift, but, continuing its vertical descent, will mark out on the board a new direction to the *right* through an angle corresponding to the original bend in the road. By continuing this process, the recorder is made to draw on the paper a facsimile of the path followed, no matter how the latter may bend and curve about.

Manipulation.—The manipulation of the instrument in short (a set of detailed instructions will be found on page 27), is as follows : after adjusting the recorder to the desired scale, place it, marking teeth *down*, upon the drawing-paper. Then close the ground glass over it, and suspend the box from the left shoulder, compass in front, resting the left hand on the knob, (see fig. 5). Commence to walk over the route, glancing occasionally at the compass, and maintain the above mentioned coincidence between needle and frame. The result is then at any time available for inspection, annotation, &c., while a little black disc with a white spot below the ground glass denotes the operator's position on the map at any instant.

CONDITIONS AND ADJUSTMENTS AFFECTING ACCURACY.

In order that the record drawn on the paper will represent a rigorously exact projection of the route actually followed, supposing such to be possible, the following conditions, considered approximately in order of relative importance, must be fulfilled.

(*a*) *The Operator's Pacing must be Regular and his Average Pace correctly taken into account.*—This point has been fully gone into in an earlier section; 3 per cent. is assumed to be about the extent of uncertainty

Fig. 5.

to be reckoned with in ordinary pacing. This error principally affects *scale;* the *shape* of the record will only suffer if the pacing is not uniform over various parts of the route.

(*b*) *The Box must be kept pointing into the Actual Direction of the Road followed.*— This is a possible source of considerable error with careless handling, but luckily vanishes with a little attention, even in inexperienced hands. It is evident that the instrument only takes cognisance of the position in which it is kept hanging during the walk. Now it will be found, as has been the experience of many who tried the instrument, that the box is carried in the easiest manner if pointing straight ahead, when it is also least affected by the movement of the body, &c. With the hand resting on the knob and feeling how that side of the box hangs, it requires but a little attention at first, which soon merges into a habit, to be able to ensure a fair agreement on the whole between pointing of instrument and direction of road. Yet the significance of this condition and the direct bearing it has on the final results cannot for a moment be ignored, and probably a large percentage of the instrument's unavoidable deviation from rigorous truth is due to this "leeway"; hence its enumeration among the foremost queries.

(*c*) *The Compass should remain Pointing to the Magnetic North.*—Sounding somewhat axiomatic, but nevertheless an important condition of accurate function. The pedograph needle's peculiarity of being pivoted in a fixed axis brings with it the unavoidable drawback that such needle is liable to be pulled out of its pointing by the vertical component of the earth's magnetism, whenever its axis is inclined. This deflecting tendency can be counteracted by the weight of the little spiral springs, adjusted in a manner described in the detailed set of instructions. On the whole no difficulty will

be experienced in obtaining a correct and permanent balance, especially since in practical use the needle-axis remains sufficiently near the vertical to render the effect of slighter inaccuracies in balance quite inappreciable.

(*d*) *The Needle-frame is to be kept in Coincidence with the Needle.*—Attention to this point is the operator's regular business during the work, the steady pointing of the needle enabling quite accurate coincidence to be attained. *In this continuous setting of the direction during the walk lies an important characteristic of the pedograph.* It amounts to nothing less than as if every bearing in a compass traverse (or compass-oriented plane tabe) were not only observed once or twice, but a repeated number of times on various points of each and every alignment. This would evidently be a way of eliminating many of the little inaccuracies which a single setting might be subject to, such as: imperfect coincidence of needle, inaccurate pointing of box, *local magnetic attraction, &c.*, the result possessing a considerably higher aggregate degree of accuracy than any single observation could lay claim to. For this reason the azimuths by pedograph, though depending on a relatively short compass-needle, are generally more trustworthy than those obtained by the smaller surveying compasses, while in the event of local attractions over small areas, the pedograph gains a considerable point of vantage over even the most accurate surveyor's compass.

(*e*) *The Compass Frame must be a true Indicator of every Movement of the Drawing-board.*—This depends evidently on the care with which the instrument is constructed. The connection is made directly over

pulleys of equal circumference by means of a loop of strong fishing-cord, with a special device for taking up the slack when necessary. On the whole it has not been found difficult to meet the above requirements with an ample margin of accuracy, it being, moreover, always easy to apply the tests which suggest themselves in this connection.

(*f*) *The Box should remain hanging from the Shoulder in one Position, preferably with the Upper Face Level.*— To render this condition possible, a little spirit-level has been mounted near the compass, by which the upper length-edge of the box can be kept horizontal, so as to afford a fixed base upon which the successive positions of the drawing-board can refer themselves. Though it is useful to observe the bubble now and then, it will be found that if the hooks on the strap are fixed into the coat over the shoulder in such a manner that the bubble remains in the centre during the first fifty paces or so, the level will be sufficiently well maintained by the mere "hang" of the box throughout a long walk. The uncertainty in this respect is estimated at about half a degree.

(*g*) *The Recorder should always descend in exactly Perpendicular Direction.* — This is what we have assumed in explaining the action of the instrument, and, as practice has showed, on fair grounds. Probably the incessant pounding of the hammer on its stop and the jars of the footsteps will not allow the low centre of gravity to remain long out of the vertical of suspension. Besides that, there is the constant setting of the drawing-board, which is another case of the series of superimposed adjustments referred to above, tending towards a more correct integration of a

number of factors. The likely error due to non-vertical descent of the recorder may also be estimated at half a degree in bearing.

(*h*) *The Mechanical Action of the Recorder should be Reliable and Uniform with regard to its Progression over the Paper.*—This depends entirely on the construction of the instrument and the correct adjustment (also looked after in the first instance by the makers) in distance between drawing-board and ground glass. Too loose a grip of the recorder might cause the latter to slip occasionally, but with the greater skill and experience which is gradually attained in the making and adjusting of the instrument before delivery, such mishaps—as also accidental "jamming" of the recorder-action, immediately perceivable through stoppage of the pulsations inside the box—are now of the rarest occurrence.

Degree of Accuracy actually Attained in Practice.

A cursory perusal of the fairly long list of possible inaccuracies given above, might lead to a less favourable anticipation of the instrument's actual performance. Such, at any rate, was the author's original impression, and it was not before a long series of experiments had amply corroborated earlier results, that the somewhat unexpected degree of accuracy which characterised these tests was finally admitted to be inherent to the system and not due to some "fluky" neutralisation of bigger errors. That such accidental neutralisation of errors does, however, sometimes occur, is proved by the fact of several closed traverses having been obtained with the pedograph, in which

the error of closure amounted to less than ½ per cent., a result, therefore, such as might be expected by methods carrying a far greater degree of refinement than any running compass survey could ever lay claim to. Instead of therefore advancing some single results as specimens of the pedograph's recording, it seems that a more correct judgment can be based upon the series of recordings in fig. 6 on Plate I., which represents, on half the original scale, *all* records (*i.e.*, not a selection) ever taken with different pedographs at various times over a certain section of road, a mile and a-half in length. For comparison, a trace of the same route, taken from authentic sources, is given at the bottom and by means of the clusters of dots surrounding each prominent corner, the locations shown of corresponding points which would have been obtained by fitting each of the sixteen instrumental records between the given terminals (A and B). Though there are evident discrepancies, it will probably be conceded that for the everyday purpose of a topographical map, any of the sixteen traces shown would have been of amply sufficient accuracy, not to speak of the self-checking record obtained by traversing a route in both directions. Nor will it probably be denied that to execute traverses with a similar amount of life-like detail by any of the methods at present in vogue, would take at least five times as long; the records in question being made at a quick walking pace. This refers of course to the simple trace of the road. When it comes to sketching-in adjoining details both methods are similarly affected, the pedograph presenting, if anything, the advantage of instantly giving the operator his exact position whenever he

PLATE I.

21.

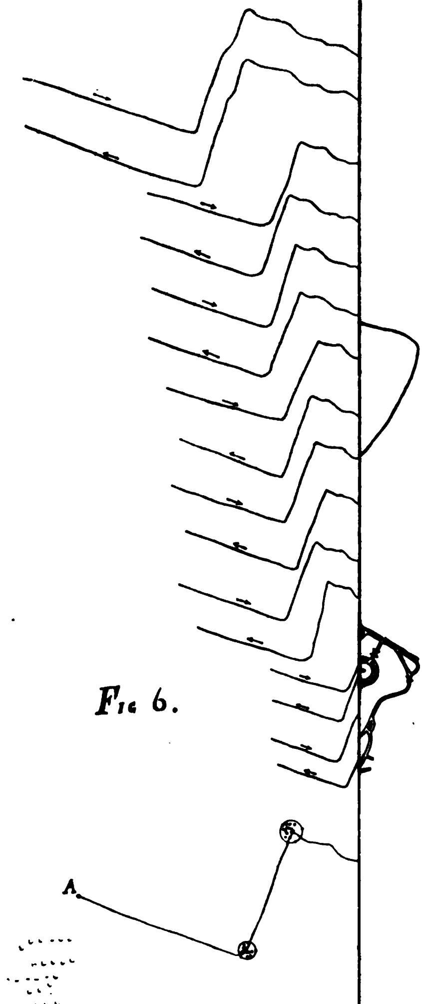


Fig 6.

stops. Thus even on a perfectly straight road, in which all the advantages of the instrument's automatic directions would be wasted, the ordinary plane-table sketcher would have to mark in his houses, drainage crossing, &c., by means of paced bits, plotted out each time; whereas the pedograph operator would merely take up his instrument and mark down his "detail" at the spot given by the recorder without using any scale at all.

AMOUNT OF PRACTICE REQUIRED FOR HANDLING.

As to the amount of practice required for a proper handling of the pedograph, it is a noteworthy fact that, though some practice is undoubtedly of advantage, the most remarkably good results have often been obtained by absolute beginners at the very first trial. Thus in fig. 7, Plate I., is shown the trace of a walk in Regent's Park, London, made by the junior partner of a well-known house of instrument makers, who had never handled the pedograph before. On returning to the point of departure, hardly $\frac{1}{20}$ inch was found to separate the extremities of the loop. Similarly, the official trial of the pedograph before the Royal Engineer Committee at Chatham, in May, 1903, was undertaken by a non-commissioned officer who was (presumably as part of the test) given not more than the barest time and chance to understand the manipulation of the instrument and then immediately sent out quite by himself on a four-mile walk round Chatham. The resulting trace closed with a hardly appreciable error (fig. 8, Plate I.). In order to show how a simple instrumental trace may be worked up into a complete

map, a reproduction[1] is given in fig. 9 of an experiment made by Herr Heer, of the Geodetical Institute, Royal Technical High School at Stuttgart.

Practical Uses of Pedograph Surveys.

To those who have known the labour and drudgery of depicting topographical features on a blank map, the advantages of the pedograph seem almost axiomatical, and it is difficult to state whether it is the saving in time or the circumventing of a mass of mental worry which constitutes its chief point of vantage. We have seen that, without aiming at high precision, the instrument produces a simple "meander" of any reasonably passable route at the rate of 3½ or 4 miles an hour with a degree of accuracy and rendering of detail which the average plane-table or prismatic-compass sketcher would be extremely sorry to see himself tied down to! Wherever such quick traverses are of use, the pedograph finds its *raison d'être.* Foremost ranks, of course, the **military** aspect. It would lead into an unwarrantable digression to consider piecemeal the varying aims and characters of military topographic work in different countries and the use that the pedograph might or might not be put to in each case; suffice it to point out that in all military organisations great stress is laid on an officer's ability (though the practice is mostly confined to the special surveying and engineering branches) to execute rapid plane-table traverses, not to speak of the more labo-

[1] Taken from Dr. Petermann's *Geographische Mitteilungen*, Gotha, 1903, Heft. viii.

rious prismatic compass methods. All this traverse work it is the pedograph's aim, in the first instance, to replace; but here it need not necessarily stop. In all rigorous topographical work, no matter how accurately the primary, secondary, or even tertiary control has been computed and plotted, one has at some time or other to face the *details*. Many treatises ignore these altogether, and leave it to the workers in the field to realise the wide gulf which separates a highly finished skeleton from the full topographical rendering required; but where the detail methods happen to be gone into, it is usually found that they consist of a great number of paced traverses over short distances, frequently controlled by known points and supplemented by eye-sketching, &c., according to the nature of the ground. In wooded districts traversing is almost the only thing to fall back upon. It is in such **detail-work of rigorous topography**, again, that the pedograph, with its economy in time, *personnel* and brain-effort, cannot be denied a sphere of usefulness. It might further find uses in a multiplicity of **survey work of temporary or preliminary value** which, for want of trained surveyors or out of regard for expenses, is often done in a very rough and useless manner, or left undone altogether. Under this category would fall preliminary surveys of localities by prospectors, concessionnaires, owners of half-developed estates, &c. Another use which had not been anticipated, but which revealed itself in many an order received by the makers, is the necessity under which owners of certain kinds of estates periodically find themselves of making **computations** of irregular and ever-changing **areas of cultivation.** On many plantations, notably in Java, the pedograph is now used

for tracing out such areas and bringing them into a shape in which the planimeter can do the rest. As to the use which **travellers and explorers** might make of the instrument, the very complex considerations governing this question do not allow of anything like a definite opinion to be offered here. Intending travellers can, however, find enough information in this booklet to enable them to judge for themselves in how far it might pay to add a pedograph to their already too bulky list of impedimenta. The matter becomes different again, where it is intended to make a protracted stay at some place of sufficient importance to warrant a little more than "exploratory" attention to be bestowed upon its nearer surroundings.

DISADVANTAGES.

It might be averred on good grounds that this little treatise cannot exactly be the place where to look for a plain statement of disadvantages inherent to the use of an instrument described in it; yet without necessarily professing to take up any other standpoint than that of decided advocacy, the author will try to enumerate here every possible objection to the use of the pedograph which he can think of or had brought to his notice at some time or other, if only in order to present the counter-arguments and point out some fallacies.

Bulk, Weight and Cost.—There is no doubt that the pedograph presents more bulk and weight than many of the smaller topographical appliances in use, and these points must therefore be duly offset by other considerations (saving in time, skill, labour, &c.), before the device can be considered of real use.

Dimensions have been given elsewhere; the weight is about 7½ pounds, which is just about the total weight of the latest 4 by 5-inch "Kodak," than which, it will be admitted, few articles of intermittent, or even very casual utility are more emphatically intended for carrying about. In *cost* the pedograph stands about midway between a good prismatic compass and the smallest transit-theodolite, which fact, apart even from considerations attached to the manufacture of new devices, would seem to reflect favourably on its price in connection with its comparative utility among kindred instruments.

Liability to get out of Order.—The recorder is a delicate mechanism and has to be handled with a certain amount of care and judgment. For some this may prove an insuperable obstacle; for others nothing more than a matter of customary precaution in handling any instrument. The personal aspect therefore predominates here. Suffice it to say that the instrument has in practice worked with good results in many a hand, its performance with practiced observers amounting to perfect reliability, and that constant efforts in manufacturing are directed towards securing the greatest possible immunity from accidental derangements.

Limited Area of Drawing-board.—Compared with the military plane table, the pedograph presents less working space on a single sheet of paper. In most cases, however, the smaller scale at which the instrument is able to work in the first instance will be found to amply make up for this loss. Such was also the outcome of practical experience, so that it has not been found necessary to increase the size and weight of the instrument to secure a larger board.

Sketching Details.—Compared with the plane table, again, the pedograph certainly misses the great facility offered by its horizontal prototype for sketching details of the ground. The ground glass, though useful for identifying points on the route and an occasional symbol, is not satisfactory for elaborate sketching. Some other methods are given in the following section, but by far the most satisfactory plan, seeing that in ninety-nine cases out of a hundred one can either return by the same road or go over the ground a second time (for contouring this is necessary anyhow), is to get the record first without troubling about the details, and then return with the traced record in the hand and sketch up at leisure; the shape of the route itself usually affording the necessary means of identifying the points concerned.

"*Uncertainty of the One Tooth*" might be a fitting designation for a peculiarity brought about by the toothed wheel which traces the record. Supposing a sharp corner to be taken while this wheel happens to rest with *two* teeth against the paper, it is evident that a few paces more or less may make all the difference as to whether the turning is done on the front or the rear tooth, which means a difference of 10 to 50 paces according to the scale worked at. Hence this uncertainty in every length measured out, which may represent an appreciable percentage on short distances. Happily, however, this error can never be cumulative, while the law of averages seems to have had the effect thus far of keeping this source of error within such small limits as to be quite inappreciable.

"*Unreasonable Objections*" represent a fair proportion of reflections sometimes raised. Their most common

ground is a pre-supposition of a far greater degree of accuracy than the instrument ever laid claim to; as if topography had hitherto known nought but instruments and methods of precision! Similarly, faults are sometimes found with the pedograph which are equally inherent to all methods it professes to supplant, such as the unreliability of pacing, &c. The question of contouring has been purposely left untouched in this book, being in reality a separate process with special instruments (aneroid, clinometer, &c.), almost invariably undertaken *after* the horizontal topography is obtained; the making of which is the pedograph's main, if not sole, object.

Detailed Directions for using the Pedograph.

(This section is a somewhat condensed reprint of a little pamphlet of instructions for users of the pedograph. It naturally contains much that has already been treated of elsewhere, and is merely inserted here for the benefit of those more particularly interested in the actual manipulation, &c.

Manipulation.—A removal of the outer cover reveals the ground glass, below which is the drawing-board, the compass-enclosure in the right, and recorder in the left top corner. *Before opening the ground glass be sure that the hinges are on top, viz., between compass-enclosure and recorder-box.* Affix paper to drawing-board by means of the brass clips at the sides. The recorder is then placed, marking teeth down, on the paper. Where to place it depends on one's own position with respect to the tract to be mapped out. As the first trials will probably be over moderate distances, say a few miles in circuit, a start may in such case be made from the centre of the paper. The *meridian line* lies parallel to the length-edge of the board, with the north end pointing towards the hinges, so that, in such position as allows of a

proper opening of the glass, the paper will always be found oriented with the north on top. The glass is then closed over the recorder and locked by pulling the spring over the pin. This causes the frame of the recorder to be somewhat compressed between paper and glass, so that it cannot move from its spot unless actuated by the mechanism. In good weather the beginner had better leave the outside cover behind, which allows the box to hang somewhat easier along the hips. Affix the carrying-sling to the coat over the left shoulder in such a way that, with the box hanging straight down on that side, compass in front, the level-bubble is seen to remain at or near its centre during the walk. Should it show a decided tendency to remain near one of the ends of the vial, correct the hang of the box accordingly. The brass pins on the strap once being properly affixed to the coat will keep the box hanging level with sufficient accuracy right through the walk. If it should be desired to reach some spot (say the starting-point on the route) without working the instrument, merely carry it horizontal, with the pins still attached to the shoulder. The same might be done when a temporary suspension is desired somewhere on the route itself, *e.g.*, walking round or climbing over obstacles. From the point where the record is to commence, let the box hang vertical, and, while keeping it pointing in the direction of the road, have a good look at the compass first. The latter, consisting of two magnetised steel needles and a strip of aluminium between them, will be found oscillating to a certain extent. Allow it a few seconds to come to rest. Then commence to walk with perfectly natural pace and attitude, and, occasionally glancing at the compass, *merely preserve a coincidence between indicator and frame, no matter how the road turns.* Always turn the handle so as to make the brass follow the aluminium indicator. In which way to turn, in order to produce this effect, is best acquired by practice. Turn the knob without hesitating, even if the brass should thereby temporarily overshoot its mark, this being actually an aid to the true vertical descent of the recorder. Neither is it necessary to keep watching the compass all the time. Coincidence once being effected, will keep true as long as the road is straight, though it is always advisable to make sure of this more than once. On the whole, whether the road be straight or curving, no difficulty will be experienced in

maintaining the required coincidence without stopping, as the needle normally remains steady during the walk. Should it oscillate moderately, a mean position can be given to the frame; in case of violent swinging, better halt a few seconds and set to a quiet needle before continuing the march. Furthermore it is necessary to keep the box pointing in the direction of the road, which can generally be done with sufficient accuracy by the feel of the hand on the knob. At the same time it is possible to keep the instrument hanging fairly steady by holding it slightly off the hips, if necessary, but otherwise let it hang quite naturally and maintain as unrestrained a carriage and gait as possible. Nor is it necessary to keep walking in bee-lines ; a little deviation here or there will have no appreciable effect.

The points to be observed during the walk are therefore : *coinciding needle*, *level bubble*, *steady box* and *pointing with the road.* —The pulsations of the recorder which can be felt inside, serve as an indication that everything is working properly. While opening the glass, hold the instrument flat. Replace the recorder carefully in its box, marking teeth down, handling it by the tail-piece only. In good light the marks on the paper are plainly visible, but gain of course by touching-up with pencil.

Further Adjustments and Functions. Balancing Compass-needle. —The peculiar system of pivoting the needle, unavoidable for securing steadiness while walking, calls for compensation and a means of adjusting to the varying nature of the earth's vertical magnetism at various localities. An unbalanced needle betrays itself by a persistent discrepancy in records over north-southerly trend, taken from opposite directions.

To balance the needle, rest the box vertically and with level-showing bubble against some solid bar or ledge (say the edge of a table) placed approximately in the magnetic meridian, and bring needle-frame in coincidence with needle. Neighbourhood of iron is of course to be avoided. Then gently incline the box sideways through some 30° to *East* or *West*, resting it against the solid edge all the while, and note whether, with some tapping against the box, the needle acquires a permanent deflection out of its frame. If so, open the slide and with a pointed bit of wood very carefully slide one of the spiral springs in the needle towards the lighter end, and repeat until no lasting deflection is observable in the needle during the test.

Scale.—The scale depends on the number of teeth of the ratchet-wheel caught and moved by each oscillation of the hammer. If *one* tooth is caught each time, the scale will be 2 *inches to the mile* ($\frac{1}{50000}$ in Metric Recorder); *two* teeth give 4 *inches to the mile* ($\frac{1}{25000}$ in Metric Recorder); and so on, till *four* teeth or 8 *inches to the mile* (*five* teeth or $\frac{1}{10000}$), the largest scale. Adjust the amplitude not wider than just necessary to catch the required number of teeth, and check the recorder's action by locking it between the boards somewhere near an upper edge, where the ratchet-wheel can be watched in its revolution. After a few shakes of the instrument, a blackened spoke of that wheel is seen to appear. From the moment this mark is uppermost, impart to the instrument exactly 50 vertical pulsations (65 for Metric Recorder), and note whether the ratchel-wheel has accomplished in that time a *full* number of revolutions equal to the number of teeth adjusted to. Every revolution of the ratchet-wheel means one dot pricked on the paper, and as the latter are spaced $\frac{1}{20}$ inch apart (1 millimeter in Metric Recorder), distances may be measured on the paper either by counting the dots or applying an inch (cm.) measure. In the above relations an average human pace of 2,000 to the mile (1,300 to the kilometer) has been assumed. Should the personal pace differ materially from the average value, a proportional correction must be applied; thus 2,100 paces to the mile correspond to scales of 2·1, 4·2, &c., inches to the mile.

Another simple and more direct way of checking the scale is to walk over a known distance and measure the displacement of recorder over paper or ground glass.

Orientation of the Record.—As already mentioned, the meridian line (magnetic) on the drawing falls parallel to the edges of the board, and is therefore represented by the folds in the paper caused by stretching it over these edges. For this it is necessary that in a position of the drawing-board (with hinges on top) in which its edge coincides with the long arrow in the box, the brass frame in the compass (arrows pointing to the rear), should lie in the "fore and aft" line of the box, as shown by the marks in the edge of the circular aperture. This adjustment must be checked over from time to time and if necessary, restored by slipping the compass-disc past the cord in its groove into the required position.

Sketching Topographical Details on the Record.—The sketching of details along the route can be done in various ways. If the tract to be mapped out cover only one sheet, all annotations can be made on the ground glass—below which the "target" of the recorder shows one's station at any moment—and transferred to the paper afterwards. A bigger tract or route-survey covering more than one sheet had better be illustrated by means of separate notes in a field-book, referring to numbered marks made on the ground glass at the respective stations.

The actual manipulation of the instrument in such cases is as follows: Whenever something has to be sketched-in, halt; if at a corner, preferably before turning it; *face to the left* and bring up the box flat without detaching the pins from the shoulder. In this position the round edge of the box points to the right, *i.e.*, in the direction of the road last followed, so that if the last position of the drawing-board has been preserved, the latter will come up at once oriented to nature, which greatly facilitates the sketching of topographical details on the ground glass, below which, moreover, the target denotes the position at that instant.

Another, often the most practical way, of sketching-up an instrumental record, is to traverse the road twice, say in opposite directions—the first time without stopping, except to mark a few points on straight pieces which could not otherwise be easily recognised from the shape of the record and, on the return trip, carry this record in the hand and work it up in the way often followed by military surveyors who have existing topographic data to work on. Meanwhile the instrument can be made to keep a simple record of the return-trip as a check on the first trace.

To Locate Points Situated off the Road.—Whenever the box is sighted towards a certain object and coincidence effected between needle and frame, a line drawn with the ruler through one's station on the ground glass, perpendicular to the upper edge of the box, will point into the direction of the given object. By repeating the operation from a second and preferably a third station, two or more rays are obtained which determine the object by intersection. In this manner one might follow one bank of a river and, while recording its course, at the same time determine the width at various points. The same method can also serve in an opposite sense to determine or check one's own station by

"resection" on known landmarks, which may be useful when circumstances have rendered the paced distances unreliable.

Limit of Recorder's Run.—The recorder cannot, of course, run on indefinitely in one direction. Should there be chance of its running off the paper or fouling one of the supports at the next curve in the road, transfer it to some other spot on the paper whence to continue its record. Some foresight has therefore to be exercised in this respect. The pulsations perceived inside the box are an useful safety-signal. Should this cease, investigate the cause at once.

Inverse Function.—The pedograph's function can also be reversed, viz., to guide a march in dark or foggy weather towards a given goal, whether in a straight line or along such routes as may be found most practicable as one proceeds. For this purpose the situation of the point aimed for is marked on the ground glass with due regard to the scale worked at and after turning this point perpendicularly below the starting-point on the glass, the march commenced into such direction as will keep the needle in its frame without changing the position of the drawing-board. Should the nature of the ground cause deviations, such meanderings are recorded in the usual manner and as soon as practicable a new start made in the direction of the goal by merely turning the latter point perpendicularly below the position at the moment on the ground glass.

Sloping Ground.—The pedograph is clearly not intended for mountainous country; a disability which it has in common with all other methods based on pacing. On moderate slopes, up to say 10 degrees, fairly accurate results may still be obtained by stepping out well up-hill and maintaining a steady stride on down-grades.

Use in bad Weather.—Rain does not affect the use of the pedograph, except that some shelter is required when opening the box. The mere drawing of the record is not affected by any condition of weather, including dense fog. With the aid of a bull's-eye lantern it can also be worked by night for reconnoitring a road unnoticed or reaching a given point.

Distance between Drawing-board and Ground Glass.—The distance between the parallel surfaces is adjusted in the factory. Be sure therefore not to disarrange any of the four screws which

determine this gauge. Should a re-adjustment prove really necessary, place the recorder successively near each of the corners and adjust the screw at that corner so that even with considerably harder jarring than the instrument would receive in an ordinary walk, there is no sign of the recorder slipping over the paper, while yet the grip is not so strong as to prevent the recorder working freely or readily assuming its perpendicular position. Be sure to lock the screws tightly into position by means of the check-nuts.

Poise of Hammer in Recorder.—The spiral spring in the recorder should have such a tension as to just overcome the weight of the hammer, keeping it almost or very lightly pressed against the upper stop. While walking, the hammer must be felt to swing through its full width, striking upper and lower stops with equal force and in regular rhythm.

Various Causes of Error. SCALE SHOWS MODERATE, CONSTANT ERROR.—Wrongly applied personal pace, possibly aided by a small deviation in distance between dots on paper.

SCALE SHOWS CONSIDERABLE BUT CONSTANT ERROR.—Recorder does not work to the number of teeth intended.

SCALE SHOWS IRREGULAR DISCREPANCIES.—Temporary disturbances in action of recorder ; slipping ; places with shortened pace (steep inclines, loose soil).

CONSTANT ERROR IN DIRECTIONS.—Wrongly oriented drawing-board.

IRREGULAR ERRORS IN DIRECTIONS.—Badly balanced needle, or accidental super-imposition of some of the following minor causes of error : Box not carried level ; not pointed with road ; needle not properly coincided ; recorder not descended quite vertically.

All constant Errors in Scale or Directions are eliminated by fitting the Record between known points on the Map.—Any of the usual methods can be applied for this purpose. In actual practice it is almost always possible to start and terminate a reconnaissance at known points, or to locate such points during the trip itself by independent observations.

THE "UNIVERSAL SCALE."

Though not an indispensable adjunct to the fittings of the pedograph, a special scale has been devised by the author to meet the cases in which odd scale values arise through a length of pace different from the assumed average. Thus a short-paced observer may find himself working at, say 2·3, 4·6 inches to the mile; $\frac{1}{47000}$, $\frac{1}{285000}$, &c. This was before further experience in practice had shown that, no matter how odd the scale, provided it be uniform throughout, the instrumental work is most likely to have been adjusted into some general map before it is necessary to measure or plot out distances on it. The "Universal Scale" therefore loses much of its original *raison d'être*, but being, as far as the author can ascertain, a somewhat novel departure in scales and very useful in many ways, a description and illustration of it is given here.

The scale (fig. 15, plate iii.) as now made by Messrs. J. H. Steward, Strand, London, consists of a strip of transparent celluloid, some 9 inches by $2\frac{1}{2}$, on which lines are ruled and figures marked in such a manner as to show at a glance :—

(1) Scales of yards (and the length of 1,000 meters) for *any* value between 1 and 8 inches to the mile.

(2) Ditto, ditto, for any scale between $\frac{1}{8000}$ and $\frac{1}{80000}$.

(3) The "R. F." or natural scale equivalent of any inch-scale between the above limits, and *vice versâ*.

It can therefore replace many of the separate sets of scales used at present, and incidentally obviates much of the figuring brought about by that thoroughly

vicious factor 1,760, which is still allowed to connect two important units of land measure, not to speak of the additional complications introduced by a mixed use of inch- and "rational" proportions.

The manner of using the scale is fairly simple: the slanting lines mark off hundred-yard spaces, a thicker line being drawn every 500 yards. Wherever these slanting lines intersect one of the parallel lines, they divide up the latter in yards according to the scale with which it is marked. Odd values can be interpolated by eye between the parallel lines. The following examples will make the use of the scale clear.

Example I. To construct a scale of yards for a Map drawn to $\frac{1}{25000}$.—Fold a strip of paper so as to obtain a sharp straight edge. Lay this edge close to scale so that it lies perfectly parallel between the horizontal lines, at a place where it cuts the scale-mark $\frac{1}{25000}$ on the right hand side. Then mark off the 100-yard intervals on the paper edge as given by the slanting lines.

Example II. To find the scale of a Map when a certain distance on it is known to be 1,000 *Meters.*—Mark off this distance on a straight edge of paper, which then lay on the scale and slide up and down, keeping it parallel to the horizontal lines until the marked interval fits between the zero line and the slant-line called 1,000 meters. The scale of the map is then read off directly on the right hand side, either in inch- or in natural values.

Example III. To construct a scale of Meters for a 4-*inch Map.*—The length of 1,000 meters on that scale is found at the place where the 1,000-meter

slant-line cuts the 4-inch scale-line. Through this spot draw or imagine a short perpendicular line, which will intersect the 1,000-*yard* slant-line somewhere below the 4-inch horizontal line. A new horizontal line drawn through this latter point (or straight paper-edge held close to the scale) will then be divided up into 100-meter intervals by the slant-lines at the required scale.

Example IV. Construct a scale of PACES (at 31 *in. to the pace) for a* 6-*inch Map*.—The length of yards at the given scale would be had by mere inspection. The paces in this case being $\frac{31}{36}$ of a yard, we have to look for the 100-*pace* intervals at the places where the slant-lines intersect a horizontal line (say the folded edge of a strip of paper) held at the scale-mark $\frac{31}{36}$ of 6 in., or 5·17 in.

It is also evident that where one happens to be tied down to a certain total length of scale (*e.g.*, 6 in. in British military sketching), a mere glance at the celluloid scale will tell the number of units which go to make up the approximate total length.

CHAPTER II.

THE CYCLOGRAPH, AN AUTOMATIC ROUTE-TRACER FOR VEHICLES.

PRELIMINARY CONSIDERATIONS.

As the instrument described in the preceding chapter gradually became known, various suggestions and queries reached the author concerning its possible adaptation to vehicles, or failing this, the construction of another simple route-tracer for use on, say a bicycle. The first idea soon proved to be impracticable, so that a thorough re-designing *ab ovo* would in any case have to take place ; while the alternative suggestion did not at first sight seem to derive much encouragement from the fact that roads, good enough for wheeled traffic, will in all likelihood co-exist with topographic data, rendering such running surveys as here contemplated, more or less superfluous. This line of reasoning, however, proved to be somewhat beside the mark, as the following explanation will show.

As explained in the chapter on the pedograph, the weakest link in that instrument's chain of functions lies in the *pacing*. Though it has been shown at the same time in how far that mode of topographic measurement is justified, and how its shortcomings under less favourable circumstances may be somewhat met or neutralised, it cannot be denied that if this

pacing could be replaced by a more reliable mode of measurement—the cyclometer-method, based on wheel-revolutions, being the first to suggest itself in this connection—an instrument would be evolved in which, even on unfavourable ground (steep slopes, soft soil, &c.) all the working factors would remain in due harmony and continue to yield results within the general degree of accuracy pertaining to the system itself. To ensure still greater accuracy, it might then further be possible to design a contrivance (as was already done in this case) by which all measured distances would be automatically reduced to their horizontal values; but after reconsideration of the errors likely to be introduced by measuring on the slope (even on an incline of 15 degrees, or *one in four*, this error remains below $3\frac{1}{2}$ per cent.), the author decided not to encumber simplicity by affixtures in which the greater refinement aimed at would probably be lost anyhow in less positive mechanical action. If it should be really necessary to calculate the horizontal values, the clinometer added to the instrument will enable such reduction to be readily made.

The ruling idea in the design of this new instrument was, therefore, *to introduce a more accurate measure of distances* without affecting the other function performed—that of recording *directions*—and with the least possible detriment to the instrument's portability and handiness. The simplest form would thus seem to be a single wheel with the mechanism mounted upon it, to be trundled in front of the observer after the style of the "wheelbarrow odometer" used in some topographical work for measuring distances only. Thoughts of real expediency, however, led to giving the instru-

ment the shape of a separate flat box, adapted for fixing to the handle bar of any bicycle, with which, whether ridden or trundled, the trace of the route can be made to develop as quickly as one proceeds. Unmounted it is surely possible to lead or push a bicycle through any kind of country where a "wheelbarrow odometer" could be used, while the bicycle offers, moreover, the advantages that it is at the same time a means of rapid conveyance to and from the field of operations; that it is not nearly as conspicuous in use; and that wherever the nature of the ground should allow of it to be used mounted, the trace of the route can be obtained at the rate of, say nine miles an hour. Hence this new instrument—the *cyclograph*—should not be looked upon merely as a contrivance for registering the route followed by a bicycle, but rather as an automatic route-tracer, based on odometer-distances, for use over any kind of country over which a bicycle can be pushed or ridden.

Construction and Working.

Shortly summarised, the cyclograph is made to work as follows: in a flat box, fixed horizontally to the handle bar of a bicycle, is contained a sheet of drawing-paper which can be kept in a constant orientation by adjusting meridian-lines, ruled on its surface, parallel to a compass-needle mounted over the box. The progression of the vehicle causes this sheet of paper to be gradually displaced straight to the rear without losing the orientation once given to it (*i.e.*, remaining parallel to itself). A small ink-roller which presses on the paper then marks on its upper surface

FIG. 10.

FIG. 11.

a line in a *forward* trend, equal to the *backward* motion of the paper. As the course curves or changes in direction, a simple manipulation of the observer turns the paper in azimuth, so as to restore parallelism between paper-meridians and compass-needle. This turning always takes place round the point of contact with the ink-roller as a centre. Hence the subsequent progression of the paper causes a deflection of the record on its surface similar to the curve or bend in the road, and so on, a facsimile of the path followed thus developing *visibly* under the eyes of the observer.

Eccentric.—The motive power is derived from a simple eccentric device fixed to the front wheel (figs. 11 and 18). A thin circular disc of steel is fitted closely against the spokes of the wheel under the fork; the hub passing through a very eccentric hole in the disc, which revolves freely with the bicycle wheel without fouling the fork or any other fixed part. Against the outer rim of the disc slides a pin, forming part of a lever, which is pivoted to the free end of an oblong plate screwed to the axle of the wheel below the nut which usually attaches the axle to the fork. When the apparatus is not in use, the lever is simply allowed to hang down without touching any moving part, and therefore not causing the least wear or friction in the daily use of the bicycle. In order to bring it into play, the lever is simply turned up to the front until the pin touches the rim of the disc, and hooked in that position to a cord which is always kept moderately taut through the force of a spring in the instrument. As the wheel then revolves, the wave-like oscillations of the disc (which, as we have seen, is mounted eccen-

PLATE II.

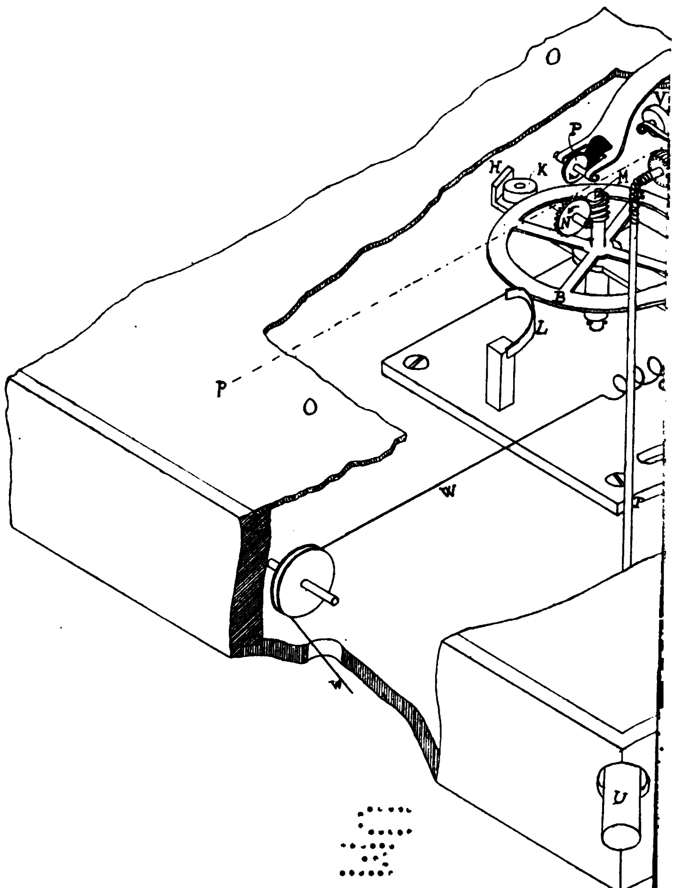


FIG. 12.

trically on the hub) will communicate themselves to the pin and thence to the lever, so that the cord is periodically pulled out through the extent of about $1\frac{1}{2}$ inches, and then let go again. How this power is made to actuate the instrument will be explained below. The eccentric here described can be attached without difficulty to any kind of bicycle, and has proved itself in fairly long practical use to be in every way as suitable as could be desired.

Mechanism.—It would be a simple matter to convert the linear power thus placed at our disposal into the circular motion required in the mechanism, by means of some pall-and-ratchet action ; but in this case it was also desirable to introduce a variable scale in the linear motion, the least adjustment of which should have its proportional effect upon the revolving parts, which can never be the case when a toothed wheel is used. For this reason the author had recourse to the old but not generally known mechanical "dodge" described below. A lever (A, fig. 12, Plate II.), is made to pivot round a vertical axis formed by the axle of the "rim wheel" (B) and can oscillate between the stops (C) and (D), the first of which is fixed and the latter adjustable along a divided scale, at any point of which it can be fixed by means of a milled screw (E). The lever is normally kept pressed against the rear stop by the tension of a spring (F), which is at the same time strong enough to keep the cord (W) leading to the eccentric, moderately taut. A pull at this cord moves the lever until it hits somewhere against the stop (D). Should at such moment the pulling action of the eccentric be not yet exhausted, its remaining force is

spent in extending the somewhat stronger spring (G). In this manner the lever always gets the exact amplitude of swing determined by the distance between the stops, which is adjustable to any value between the maximum width and *zero*. The scale-divisions are marked quite arbitrarily and merely serve for approximate adjustment, the exact scale being determined in the more direct manner described below. Now the lever carries on opposite sides of the pivot two upright bits (H), the smooth inner faces of which form wedge-like openings with respect to the smooth rim of the wheel (B). In these openings two little smooth circular discs (K) are kept mildly wedged by the pressure of light springs (not shown in the drawing) fixed to the lower surface of the lever. These little discs are therefore always in contact with the rim and the inclined planes (H). The effect of this arrangement is somewhat surprising; any movement of the lever in the direction from D to C will cause the discs (K) to merely slide along the rim with very little friction, so that a light friction-spring (L) is amply able to keep the rim-wheel immovable. The least attempt, however, to reverse the motion of the lever meets with instant reaction on the part of the discs which, though quite smooth on the edge, immediately "grip" the smooth rim and carry it round with them with a force amounting to an absolute jam. The reason of this is quite plain: the lever's motion in one direction tends to roll the discs slightly out of the wedge, while in reversed sense a turning couple is set up which wedges them into the narrower part, so as to produce an effect of what appears like an instantaneous locking action. Nor is it necessary that the parts should be constructed with

anything like great precision, the author having seen quite roughly-made models answer infallibly. For additional security the lever is provided with two such "gripping" actions, each working independently. The result of this arrangement is that the *least* adjustment of the stop (D) will have its effect upon the place where the rim is gripped; hence also on the *number of oscillations of the lever which will bring about one complete revolution of the rim-wheel.* The smallest number of oscillations to have this effect is *ten;* the largest, say, about 300, while practically any value between can be reached after some trying.

Scale.—These numbers are a direct function of the *scale* on which the survey is drawn. Each oscillation of the lever, as we have seen, means one revolution of the bicycle wheel or, subject to more accurate individual determination, say 7·3 feet over the ground. Now the rim-wheel carries on its axle a double-threaded worm-screw (M), engaging in the teeth of the "feeder" (N). These teeth also project slightly above the surface of a plate (O) (represented as mostly cut away in fig. 12) through a slot in that plate. The sheet of drawing-paper is simply laid on this plate so as to rest on the teeth of the feeder. A mere shutting of the outer cover then brings the inked "marker" (P) to press upon the paper at a spot immediately above the feeder. As the latter then slowly revolves under the influence of the worm in the direction shown by the arrow marked in the sketch, its sharp teeth cause the paper to move in the same direction over the plate (O). The marker (P) being provided with ink from a small felt pad against which its edge keeps rubbing, will then

describe a line on the paper which coincides with the marks pricked in its lower surface by the feeder. These marks are one millimeter apart; hence *one millimeter on the paper represents as many times* 7·3 *feet on the ground as it took lever-oscillations to give the rim-wheel half a revolution* (since the worm-screw has two threads). The scale might in this manner be adjusted to *any* value between $\frac{1}{100000}$ and $\frac{1}{\infty}$; but in practice it will hardly be necessary to exceed $\frac{1}{1000000}$ as smallest scale. A simple calculation will give the data for obtaining scales expressed in inches to the mile. The actual adjustment is effected mainly in an empirical manner after calculating the number of pulls on the cord which must cause one revolution of the rim-wheel (see detailed instructions at the end of this chapter).

Directions.—We have seen that the paper is held at one place between feeder and marker. It could therefore be easily turned round this point as a centre, after which its further progression would cause the marker to strike out a new direction; but for this very reason it is necessary to make sure that such turning of the paper does not take place of its own accord through jolts, friction on the plate, &c. This requires some action to enforce parallel displacement to the paper, which action must be capable of temporary suspension in case it is wanted to turn the paper in azimuth, and *vice versâ.* In order to avoid this threatened complication (every complication being regarded as tantamount to prohibition) it occurred to the author to combine the above seemingly antagonistic functions in a simple device, which we may call

the "drag," the main part of which is a wheel (R), connected by means of a flexible joint (S) and a shaft (T) with a handle (U) projecting out of a corner of the box, within easy reach of the operator's right hand. By taking this handle between thumb and finger, either a fast or a gradual motion can be imparted to the wheel (R). This wheel also projects through a slot slightly above the surface of the plate (O), but is placed at right angles to the feeder. It is milled with sharp edged grooves upon which the paper is kept pressed by a smooth roller (V), mounted to a spring fixed to the lid of the instrument and closing down upon the paper simultaneously with the marker. The sharp grooves in the drag (R) will readily allow of the paper being pulled between it and (V) in a direction parallel to the grooves, *i.e.*, the longitudinal direction q-p in which the feeder tends to move the paper, but offers much resistance to any motion across the sharp edges. Hence an eventual revolution in R will carry the paper with it, the roller (V) simply turning in the same direction without hindering this motion; but since the paper is also kept pinched between feeder and marker, the latter point becomes a pivot round which it is turned in azimuth by this *active* agency of the drag. The *passive* function of the drag consists of a light dragging resistance which, acting behind the feeder on the line (q-p) in which the movement takes place, proves to be amply sufficient for keeping the paper in constant orientation. These active and passive functions can exist simultaneously; hence *while* the paper is being turned in azimuth its progression can continue unhindered and *vice versâ*. It is evident that the mere revolution of the paper, taking place always round the

marking point as a centre, does not of itself affect the record, but any subsequent progression will cause the line to be drawn into the new direction.

Compass.—From what precedes it is fairly evident that if we can now only keep the sheet of paper in a fixed orientation with respect to the ground, the record drawn on it by the marker—always trending forward in the direction of the vehicle's motion—will become a reproduction of the route followed; the results being arrived at in the most direct and positive manner possible. In order to secure such constant orientation, the author has, *faute de mieux*, again had

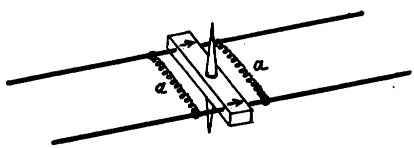


FIG. 13.

recourse to the compass. That it would be no easy matter to keep a compass-needle steady on a light and jolting *steel* vehicle, was to be foreseen. By using a double-pivoted compass needle, however, after the pattern employed in the pedograph, in conjunction with a special design of support to minimise the effect of vibrations and jolts, a system was finally arrived at which gave results exceeding all expectations, the needle remaining almost perfectly steady or acquiring only very moderate oscillations on the roughest of country roads. Such a compass is represented in fig. 13. Two magnetised steel needles are

connected by a wooden cross-bar to the perpendicular pivot, sharp at both ends. Two light sliding springs (*a*) allow of the necessary adjustment in balance, as explained in the preceding chapter. The sharp steel points rest in agate caps mounted in the circular glass cover and bottom of a compass-case (see fig. 10). With the compass held somewhere above the instrument, it is an easy matter to adjust and keep the paper-meridians—visible through the glass cover and bottom of the compass—parallel to the needles, this being, in fact, the manipulation performed during the trip by turning the handle (U, fig. 12) when necessary.

Compass Support.—In order to secure immunity from disturbing influences of the bicycle's own magnetism, the compass has been placed at a height of about ten inches above the instrument, at which height the author has not been able to detect any appreciable deviation of the needle on various bicycles tried. There now remained the effect of vibrations to be overcome. Anyone who has tried riding with a compass attached to a bicycle over an ordinary road, will appreciate what this means. While in the pedograph, subject only to the jolts of an ordinary walk, the double-pivoted construction appeared amply sufficient for ensuring steadiness in the compass, such was still far from being the case on a vehicle, though a vast improvement over the ordinary kinds of compasses tried. After a long series of experiments, in which almost every kind of compass was given a turn, attention was finally directed to the supports themselves in order to construct these in such a manner that the most noxious vibrations would not

be transmitted at all. In this particular case, the worst vibrations proved to be the horizontal component of variously inclined shocks and tremors, all lying in the median vertical plane of the vehicle; hence the compass is mounted on a rectangular frame bent out of a brass rod as shown in figs. 10 and 11, which is hinged to the cover of the instrument so that it can be folded down flat on the box. The compass is held in trunnions at the upper end of this frame and kept parallel to the box by means of two additional metal strips which, in conjunction with the main support, act like a hinged parallelogram. The whole system can therefore rock backwards and forwards in the median plane, the compass always remaining level. Normally it is held in upright position by means of a spiral spring, stretched between the perpendicular sides of the main rectangle, and able to slide up and down between them. The centre of the spring is attached to a brass stirrup, fitting over a short upright pillar rigidly attached to the box. By unshipping the stirrup from this pillar the whole device can be made to fold down quite flat over the cover. Moreover, we have a means of adjusting the force with which the spring keeps the support upright; which is to slide the spring higher or lower on pillar and supports. The horizontal longitudinal vibration, dampened by this play in the supports, though by no means all, appears to have been all that we needed to reckon with in actual practice; the first trials with this support meeting with complete success. A further remark as to the considerations which led to adopting the kind of spring described above, may be of some interest. We had, namely,

to deal with *jolts* and *vibrations*. The former, of course, vary considerably in force and frequency and require for their deadening a very stiff spring and much friction in the moving parts, so as to prevent the whole system from acting like a pendulum for some time after each jolt. The vibrations, on the other hand, are much more regular in occurrence, period and amplitude, but also appear to be far more pernicious in their effect on the needle. They require for deadening a very *light* spring and easily moving parts. We thus require at the same time a stiff and a light spring; both little and much friction in the pivots. A stiff spring would communicate vibrations to the compass and a light one would not support the weight of the compass in case of heavy jolts and sudden heaves. Happily, however, there was a way of combining the two requirements. As the spring is now stretched between the supports, its initial power to prevent deflection is practically *nil*. Only when inflected it begins to work and that with a rapidly increasing force as the angle between its two halves differs more from 180 degrees. Hence in perpendicular position the supports are very sensitive for dampening light vibrations, tremors, &c., while in case of a sudden jolt or shock the spring can develop sufficient force to keep the amplitude of swing within reasonably small limits. As to reconciling the different kinds of pivot-friction required, it appears that the presence of *eight* pivoting points in this case, each with its own retarding influence, effectually prevents the system keeping up a pendulum action of its own. Yet the compass itself has sufficient weight and inertia to overcome the friction of the

pivots when opposing its mass to lighter vibrations communicated to the base.

MANIPULATION.

The practical manipulation of the cyclograph, after being attached to the bicycle by means of a special bracket and coupled-up with the eccentric, is very simple indeed. The lid is opened and a sheet of paper, taken from a stock of sheets previously cut out and ruled like the sample shown in fig. 14, at somewhat

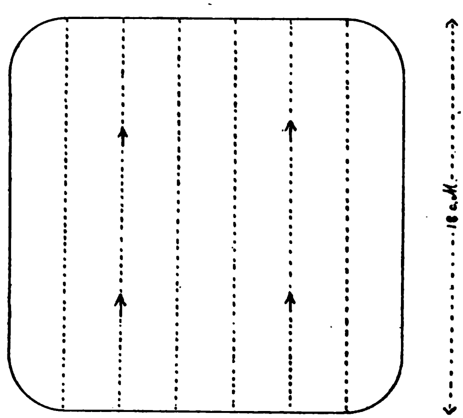


FIG. 14.

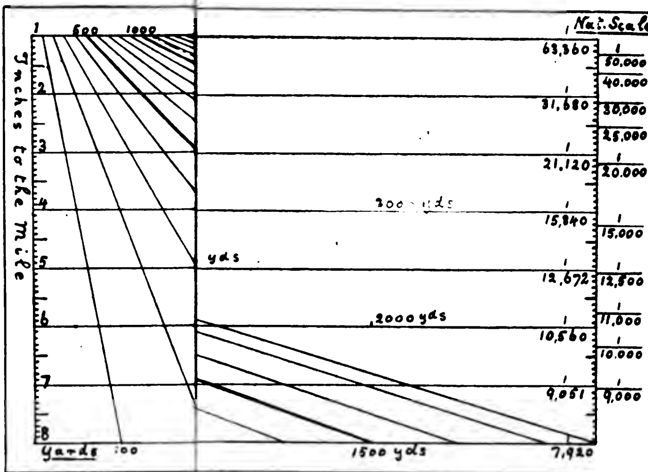
less than one-third size, simply placed *loose* on the drawing-plate. Closing the cover, as we have seen, at once brings the marker and the drag-roller to bear with the right pressure on the paper and the instrument is ready for instant use. Whether trundling or riding, the observer merely keeps the paper-meridians,

of which some are always visible below the little glass window in the lid of the box (see fig. 10), parallel to the compass-needles, with the arrows pointing the same way. **The drawing will then develop quite visibly as one proceeds.** At any time the window can be opened (which does not affect the grip on the paper) and any details along the route sketched next to the inked record, the marker always denoting one's station at the last moment. The sheet of paper thus at the same time serves the purpose of a plane-table, on which, besides the automatic route-trace, various positions may be determined by simple intersection, &c. Should the record approach the edge of the paper, the operator remains fully aware of the fact, so that he can keep "hugging" one of the edges as long as practicable. When necessary, he merely opens the cover of the box and so doing immediately releases the paper, which can then be replaced by a fresh sheet or merely shifted so as to continue the record from another spot. The latter operation is so simple that the author has often performed it without dismounting. In order to secure to the paper the biggest possible room to swing round in, a narrow slot—widening out inside—is left between the box and the cover, only of course interrupted at the four corners. The paper thus gets swinging room in a circle determined by the *diagonal* of the box. To further lop off useless dimensions, the sheet is rounded at the corners. In this manner a sheet of paper a little over 7 inches square can be used in a box 12 inches square, both of which have proved to be very suitable dimensions in practice. Later models of the instrument have a clinometer attached so as to show the longitudinal inclination of the box at

any time. The clinometer readings can then be used either for correcting distances on slopes, or for sketching contours. If the British military system of contouring is used (with scales of "horizontal equivalents") the contour lines can be sketched directly in the instrument across the record line itself. Another method is to mark the record line with the degrees of slope, *plus or minus*, occurring from time to time.

PRACTICAL RESULTS OBTAINED.

The results thus far obtained are limited to a series of trials made with the first working model of the instrument in the course of a few months, and a few trials with newly manufactured specimens. After some improvements, records were obtained like the traverse reproduced in fig. 16, Plate III. The thick line there represents, on even scale, the record drawn in blue ink by the instrument, while below it is a tracing of the same route, taken from the Ordnance Map. This trip led over fairly good country roads, some six and a-half miles in all, at the rate of nine miles an hour, which doubtless "beats the record" for rapid road surveying, especially since the accuracy of the instrumental trace in this case comes *very near* that of the existing map. That there is no reason why such accuracy should not be representative of the average performance of a well-adjusted instrument, may be inferred from an analysis of the conditions under which a faithful representation of the road followed will be obtained. These are (*a*), that the compass remain pointing truly to its meridian; (*b*) that the paper-meridians be kept parallel to the compass-needles, and (*c*) that the paper progresses in


Nat. Scale
Inches to the Mile
1
2
3
4
5
6
7
8
600
1000
Yards
100
1500 yds
7,920
2000 yds
yds
1/63,360
1/31,680
1/21,120
1/15,840
1/12,672
1/10,560
1/9,051
1/50,000
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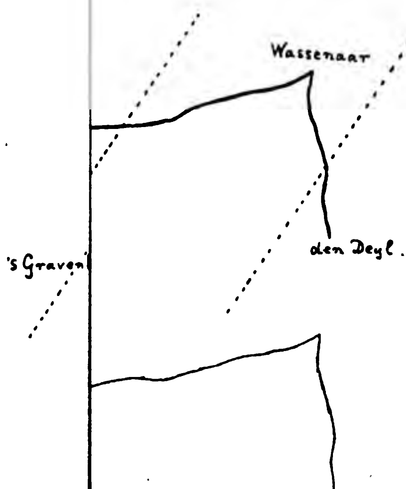
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true and constant ratio according to the distances (strictly speaking, projected distances) passed over. The first condition is easily attained within, say half a degree with any well constructed compass, granting that the bicycle's own disturbing influences have been sufficiently out-distanced. The second condition is obtained and constantly verified by the observer in the most direct manner possible. Since the plane of the compass always remains parallel to the paper, it does not matter at what angle the needles are viewed against its surface. The third condition (apart from the question of slopes, treated in an earlier section) depends on wheel revolutions and a few simple and easily checked mechanical functions, and would therefore also seem to have a good chance of fulfilment within, say 1 per cent. of accuracy.

As to the influence of less favourable ground, it is evident that such would primarily affect *speed*, causing it to drop to the rate of an ordinary walk (which is in any case from three to five times as fast as a road sketch by the old methods). As to *accuracy*, apart from the known effects of sloping ground, there need be little to cause deterioration. On very unfavourable ground, away from roads, it may perhaps be impracticable to keep setting the drawing-paper *during* the walk. In such case it is always possible to set it at an occasional halt, aiming each time for the next general direction, or a special point selected to march upon.

Use in Hydrography.

With some minor alterations, the cyclograph can be easily adapted for use in hydrography for survey-

ing rivers, creeks, coasts, lakes, &c. The box may then be increased in dimensions so as to accommodate a bigger sheet of paper, which is always convenient, and the compass question would become a much simpler one, seeing that there would be probably no need for either providing a springy support or using the double-pivoted needle. A simple compass-needle pivoted in a box with glass bottom would then suffice. The question as to the use of gimbals for suspending the whole apparatus would have to be left to the practical exigencies of each case. If a double-pivoted needle is used, the gimbals might be dispensed with altogether. The motive power can be derived from a log trailed behind the vessel, as described in the next chapter, or by providing the propeller-shaft (if a steam launch be used) with an eccentric disc against which a rocking lever is kept applied, so as to obtain the reciprocating motion necessary for pulling the cord. The influences of leeway, tides and currents, &c., would have to be attended to in a manner similar, if not quite identical, to that described in the next chapter.

DIRECTIONS FOR USING THE CYCLOGRAPH.

Erecting Compass Support.—Bolt the separate rod upright to lid of instrument ; turn up compass support and slide spring with stirrup over the erect rod. The latter need not be unbolted again, unless for packing.

Bracket.—Attach bracket to handle bar of bicycle as shown in fig. 17. Keep cross-bar as high as possible on handle bar. Bring plate to a level by means of set-screw, after which tighten up nuts. Screw up everything as tightly as possible.

Eccentric.—Attach disc to spokes as shown in fig. 18, the inner circle being concentric with the hub. Bolt to crescents laid

Fig. 17.

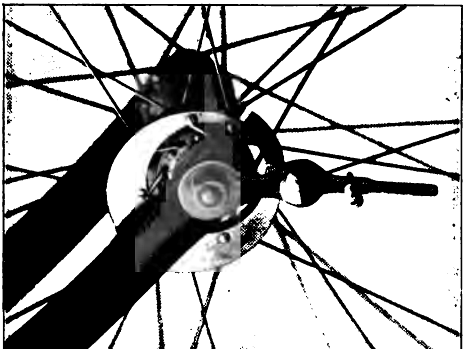

Fig. 18.

against spokes on the inside. Revolve wheel and see that disc passes freely under fork and runs true. Attach knee-plate to axle of wheel outside fork in position shown. Adjust pin to depth at which it can slide along outer edge of disc without danger of sliding off or touching spokes. When not in use, simply let lever hang down. The bicycle can then be used for years without noticing eccentric at all. When in use, keep rim and pin *lubricated.*

Mounting Instrument.—Lay box square to front wheel upon rubber cushions. Attach to bracket plate by screw entering from below. Do not omit the heavy "washer" of this screw. Before tightening up, adjust box quite square and slide it with screw as far back as possible. This will save strain on fittings. Then *tighten up* screw. Have everything snug and tight, and avoid all rattling. Investigate any rattling that may occur on way. Keep cover hooked down and window locked by revolving knob.

Coupling-up.—Turn up eccentric lever to front until pin touches disc, and revolve latter so as to get pin resting against its narrowest part. Lever is then at its highest. While there, hook to cord and take up all slack without pulling oscillating beam in instrument away from its rear stop. Then let bicycle wheel revolve and make sure (by ear and eye) that beam in instrument hits front and rear stops quite unmistakably. Hook cord to such hole of eccentric-lever as will cause no exaggerated extension of front spring after beam has hit front stop, but rather have it a hole too far than one too near the pivot, since cord may stretch. While at work be sure that beam continues to strike both stops quite audibly. Should there be any doubt about this, dismount and make sure by lifting up and *spinning* front wheel; adjust cord if necessary.

Scale. Roughly.—One *millimeter* on paper represents half as many times 2·15 *meter* (riding circumference of 28-inch wheel) on ground, as it takes pulls at the cord to cause one revolution of rim-wheel in instrument. Hence if this be *n* pulls, the scale will be $\frac{1\ \mathrm{mM}}{\frac{1}{2}\,n \times 2{\cdot}15\ \mathrm{M}}$ or $\frac{1}{1075\,n}$. We may, however, not assume that dots marked on lower surface of paper are exactly one millimeter apart, nor that wheel-circumference is always 2·15 meter. Therefore measure space covered by 10 or 20 dots in line and find mean interval in millimeters, say 0·95. Then find effective wheel-

circumference (preferably by riding over known length of road) expressed in meters, say 2·16, and work out $\frac{0 \cdot 95}{\frac{1}{16} \times 2 \cdot 16}$, which gives 8·8. Call this the *Scale Constant.*

If it is now wanted to work on a certain scale, express in natural fraction, say $\frac{1}{n}$. Divide *n* by 10,000 and multiply result by Scale Constant. *This gives number of cord pulls which must produce one revolution of rim-wheel in instrument in order that desired scale may be produced.* Adjust stop until this number is obtained, the beam being heard to hit front and rear stops each time. The rim-wheel is watched through slot in brass plate. Bring arrow on rim opposite mark and count number of pulls which will bring it there again, estimating fractions as nearly as practicable.

Preparations for the Trip.—After adjusting for scale and coupling-up, make sure once more that on revolving the front wheel, the two clicks are distinctly heard inside the box. Open cover and lay a sheet of paper from stock provided on the plate. Choose point of departure with reference to direction it is intended to take and lay this point over the toothed wheel ("feeder"). Close lid and the instrument is ready for use. Point bicycle in direction of road and turn handle, which projects through corner of box and can be pulled out somewhat, so as to bring meridian lines on paper parallel to compass-needles ; the arrows on paper and needles pointing the same way.

Manipulation en route.—Ride or trundle according to ground. Watch compass from time to time and maintain parallelism between paper-meridians and needle. If needle oscillates much, check by pressing on button in centre of glass cover. This can also be done while riding. If button is pressed smartly at the right moment, the needle will come to a dead stop. On the whole, the compass should be steady ; swinging the exception. With moderate swinging adjust meridians to mean position. Usually paper can be set while walking or riding, but on difficult ground it had better be set at an occasional halt, each time aiming for the next general direction or a special point selected to march upon.

Sketches and Notes.—Opening little window gives access to paper for sketches, notes, &c., without releasing it. Opening the lid releases paper for shifting record to new spot or replacing by a fresh sheet when record has approached too near edge. Since paper is always in view, the edge can be hugged as long as pos-

sible. Rough plane-tabling can be done on the sheet; determining positions off the road by intersections, &c.

Catching of Paper in Turning.—If corners of paper are curled up they may sometimes catch in slot round box, so that handle will not turn it. Open little window and force paper round by hand, after which handle will again be able to do the needful.

Clinometer.—The clinometer can be shipped on the box or unshipped, as required. If intending to use it, place bicycle on a level bit of ground and bring clinometer to read zero by adjusting set-screw below bracket.

Adjustments.—The above supposes adjustments to have been correctly made as follows :—

Balancing Compass.—Get compass to point across box—*i.e.*, parallel to line joining hinges on lid—and turn up lid, by which compass will be inclined to E. or W. See if needle deflects; if not, or only moderately, it is adjusted; if much, notice which (N. or S.) is the lighter end. Open slide in compass case, and with a bit of thin brass wire with hooked point, wedge the spiral spring on the lighter side away from the wood. Try balance again and repeat adjustment until satisfied. This is a somewhat delicate manipulation, but worth attending to. If adjustment is once attained, it will require no more looking to except on considerable change of latitude.

Adjusting Place of Marker.—The marker (inked roller) must rest exactly upon teeth of feeder. Ascertain by looking through slot between box and lid, both from side and front. To adjust place of marker, loosen screw on lid behind window and through opened window (leaving lid shut), adjust marker to its right place. Then tighten screw again. If a *very thin* blue line is drawn on paper, the marker does not rest squarely on teeth of feeder.

Adjusting Tension of Marker and Drag.—The drag-roller must press heavily enough to ensure paper being turned unfailingly, but this turning power is not supposed to be equal to forcing the paper round in case a corner should catch anywhere. This pressure of drag will probably never require looking after, being once adjusted in factory. Pressure of marker should be decidedly stronger than that of drag, as tested by lifting them alternately with the finger. Examine marks pricked in back of paper. If there is any sign of slipping or tearing, the drag is too strong or the marker too weak. Strengthen the latter by lifting screw under its spring.

Tension of Spring in Compass Support.—The higher the spring with stirrup is adjusted on the erect rod, the stronger it acts. Sometimes a weaker (lower) spring is useful, but for rough ground keep it quite high. If the compass acts like a pendulum (rocks about three or four times after each jolt), tighten up long thin screw connecting sides of main rectangle below compass; this increases friction in trunnions.

CHAPTER III.

THE HODOGRAPH.

A DEVICE FOR AUTOMATIC REGISTERING OF COURSES AND DISTANCES ON WATER.

WHAT LED TO PLANNING THE HODOGRAPH.

THIS instrument was designed by the author as an aid in mapping some of the extremely intricate systems of creeks and waterways which are a characteristic feature of the delta of the Yangtsze River, China. Most of the creeks nearer the actual estuary of that great river meander about in a very erratic manner, being the outcome of natural channels of drainage which developed and deepened out as the surrounding alluvial country was gradually formed and raised around them. Being open to tidal influences, their waters are constantly in motion, which tends in the course of time to still more exaggerate the sinuosities. In the lake districts lying west of Shanghai, on the other hand, tidal action is no longer felt, while the nature of the creeks in those regions resembles that of canals, being originally mere passages through vast reed-covered shallow lakes, held open by passing boats and dredged by countless craft for the sake of their fertile mud. So they remained open water long after the reed banks had become firm soil, which explains the absence of sinuosities in the

creeks of these districts, more than made up for, however, by their vast number and countless intersections.

With the exception of general trends of drainage, appreciable only at certain places, these waters are mostly devoid of current, which accounts for the great and sudden changes in cross-section found at many places. While current as an eroding agent is mostly lacking, wave and ripple take its place in a very effective manner, which is noticeable wherever somewhat bigger expanses of water allow the prevailing winds room to send a goodly ripple upon the soft and yielding lee-shores. Constant changes in configuration of creeks and lakelets (all equally shallow) are therefore occurring, unless checked by the land-owners with the aid of stone breakwaters or simple piling. In other places the encroaching of the waters goes on apace, so that it must occur sometimes that breaches are made into channels fed by a somewhat different drainage basin. Thus there is every reason to suspect that the river which brought Shanghai its importance as a shipping port owes its very existence to water pirated in this manner from another stream which has sadly degenerated in consequence.

The above discursion may lead to some understanding of the kind of country which—though a centre of a teeming population, vast trade interests and much sport and pleasure-tripping on the part of foreigners, who mostly feel their way about in their own house-boats—is, topographically speaking, as absolutely devoid of maps as ever any country was. The geographical data on which China atlases are based are derived from old Jesuit surveys, supplemented by more recent travel, coast survey, &c., but

for actual topography (with the fewest possible exceptions) one has to fall back upon native cartography, a curious mixture of fact and fiction, proportion and disproportion, useful as a rule only for the mere names found on them. This being the case, any survey, however cursory and rough, provided it be based on true scientific methods, is not only highly acceptable, but stands a good chance of finding itself the recognised standard withal, for years to come ; for the machinery of complete topography is slow and costly. Yet, to be of any use to those who leave the beaten tracks, a map must possess a sufficient amount of correct detail to enable the route followed to be identified at any point and other routes projected, if necessary, with a reasonable chance of their ultimately being found as practicable as the map makes them out to be. It was with the object of obtaining such detailed route-surveys (in this case of the creek-ridden parts of the Kiangsu province) that the instrument described in this chapter was thought out and constructed.

Functions of the Instrument.

The object of the hodograph is to facilitate the construction of running surveys by water—say, detailed water itineraries—by means of a self-registering of the mathematical elements (courses and distances) which constitute such survey. To do so by the methods hitherto in vogue, requires the constant attention of a separate observer, if, indeed, on such creeks as described above, the work in its full scope and detail might not prove to be perplexing beyond human endurance. Whether or not this be the case, and

whether or not such running surveys could with equal satisfaction be undertaken without its aid, it is a fact that the hodograph has been instrumental in the construction of at least two maps[1] of watercourses, lakes, &c., which the author would never have thought of undertaking without the aid of that instrument, it being more than likely that,—single-handed as he was—the work would have occupied as long in every-day labour as it now took week-end and holiday trips to accomplish; about forty trips to each map. Fig. 25 shows a small portion of one of these hodograph-surveys, somewhat reduced from its original scale. This was before the instruments described in the foregoing chapters were thought of. Should such work have to be undertaken again, the author would probably use or recommend the water-adaptation of the cyclograph, mentioned at the end of chapter ii., the extremely direct manner of indication employed in the latter instrument, *producing the results immediately in chart-form*, being undoubtedly more than a match for the entirely automatic action of the hodograph, which produces only a continuous record-slip for working up into a chart afterwards. As an automatic device for registering courses, however, it retains a certain amount of value, while many of the devices employed for its working, neutralising the effect of lee-way, currents, &c., would have to find due attention in *any* system of automatic "dead reckoning." A complete

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[1] 1° *Map of the Waterways near Shanghai*, by the author; scale 1 inch = 1 mile; Kelly and Walsh, Shanghai, 1901. 2° *Map of the Country round Soochow*, by the author; scale 1 inch = 1 mile; Kelly and Walsh, Shanghai, 1902.

description of the instrument and its manner of working is therefore given in the following pages.

CONSTRUCTION AND WORKING.

The ships' patent logs, now in general use, are familiar to everyone. Such a log can by a simple contrivance be made to unroll a continuous strip of paper in such a manner that the lengths of ribbon unrolled are proportional to the distances travelled over by the vessel, irrespective (within certain limits) of the speed at any time. This is the first function performed by the hodograph and thus it primarily records *distances.* Taking the edge of the paper ribbon, which has an uniform width of 3 inches, to represent the *line of ordinates* as a measure of the length of ribbon, and hence of distances made good by the vessel, we can assume any line drawn rectangularly across the width of the paper to represent the *line of abscissæ* which is then available as a measure of the other element to be recorded, viz., *directions.* The measure of directions or courses being a circular one, it was necessary to find a simple way of expressing angular motion in rectilinear values, so that an angular unit on any part of the circle corresponds to a fixed linear measure on any part of the line of abscissæ. There are two ways of accomplishing this, viz., by drawing a screw-line on a cylindrical drum mounted on the axis of the said circular motion (which principle is applied at some observatories for recording the direction of the wind), or by drawing a spiral line on a plane surface fixed perpendicularly upon the same axis. This method is applied in the hodograph.

Thus we might provide a compass-needle with a strip of some light material bent in the shape of a spiral and attached to the needle in a horizontal plane. One extremity of the spiral might be fixed to the needle at a point lying in its northerly magnetic axis at a distance, say d from the centre, and the spiral further shaped in such a manner that it cuts the magnetic East, South and West bearings at a distance from the centre equal to $d + a$, $d + 2a$ and $d + 3a$ respectively, while its other extremity is fixed in the North bearing, again, at a distance $(d + 4a)$ from the centre, $4a$ being equal to 3 inches, the width of the paper ribbon. If the line of abscissæ, *i.e.*, any line across the width of the paper, is brought under the spiral and placed in a radial line through the centre, with the nearer edge of the paper adjusted at a distance d from the pivot, the spiral can be made to touch the paper on the said radial line and leave a mark there. From the place across the width of the paper where this mark is made, the bearing of the radial line is then at once arrived at, which determines at the same time the position in azimuth of the instrument; hence also the direction of the ship's head at the moment the mark was made. This completes the second function of the hodograph :—*to mark on the gradually unrolling paper the various directions in which the vessel is proceeding.*

Fig. 22 shows the *compass-magnet*, which actually consists of a steel clock-spring bent in the spiral shape sketched above. This plan proved in reality to be a better one than fixing a strip of another material to a straight needle, since by magnetising the spring itself most of the weight can be made effective in fur-

nishing the required directive force. One end of the spring is attached to a small brass centre bearing the usual compass pivot-cap, while the remainder is held in the required shape against its own spring-force by means of threads of various lengths leading to the centre plate. The author has not found it possible to force the spring into the exact theoretical shape, but has been content with a near approximation, eliminating the errors which would be thus caused by giving the "dummy compass," described afterwards in the plotting of the record, the same slightly irregular shape. In order to counterbalance the excess of weight caused by the overhanging spiral, a brass bar, furnished at the end with a weighted screw-nut, is also attached to the centre-plate, thus forming an adjustable counterweight which serves to keep the magnet poised in a horizontal plane. At first sight this device might appear rather frail and easily distorted, but in reality the specimen here depicted has retained its exact original shape after almost two years of constant use. It is magnetised by stroking with a steel magnet, according to a system which will produce three poles, two north-pointing at the extremities and one south-pointing pole somewhere on the spiral diametrically opposite. This arrangement of three poles seems to afford the greatest directive force, as measured by counting the number of oscillations per minute of the magnet when left free to swing.

Fig. 20 shows the *principal mechanism* laid bare. On it will be seen three rolls mounted on horizontal axes between the triangular walls of the frame. The hindmost of these rolls is the one which carries the stock of paper ribbon, which is pulled off it and

Fig. 20.

Fig. 19.

doubled over a slim guide-roll placed somewhat higher in the frame, after which the paper passes down again to another roll with a roughened surface

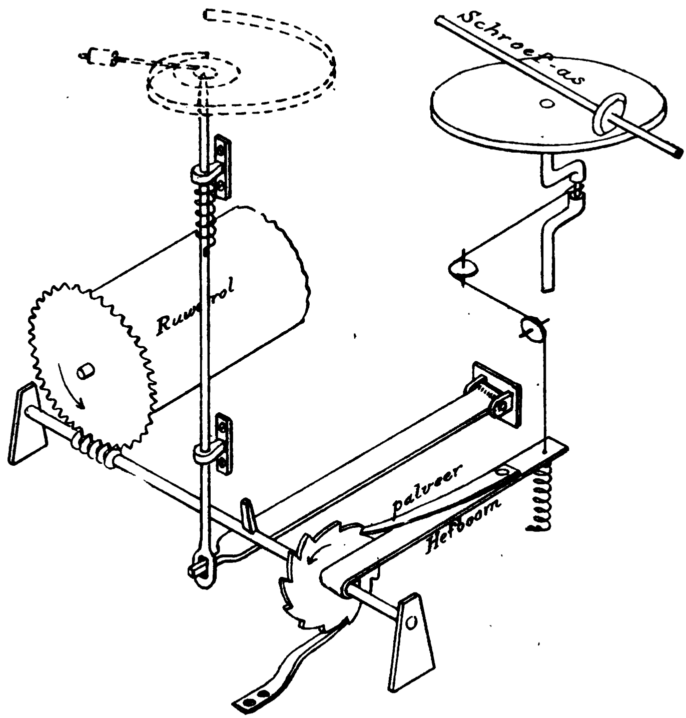

FIG. 21.

against which it is kept pressed by two smooth springs below. It is the turning of this latter roll which moves the paper, pulling it over the guide-roll and

pushing it out of the frame through a slot at the bottom. In order to do this the rough roll has a cog-wheel of somewhat larger diameter fixed to it on the same axis, the cogs meshing into a worm-screw on a horizontal shaft below it (see fig. 21). This shaft carries at its other extremity a wheel with twelve teeth all pointing one way, into which a lever engages which can be made to oscillate and thus advance the latter wheel by one tooth at a time. Normally it is kept in one position by means of a light spring, but in order to work the mechanism this lever has a thread attached to it which can be alternately pulled and released so as to cause the required oscillation. The thread is led over a little pulley fixed above the lever, and thence over a second pulley mounted at the centre of a bar (see fig. 20) by which the frame is suspended in the gimbals, for, like any ship's compass, the entire mechanism has to be thus suspended to enable it to retain its level, and if it is to be connected by a thread with fixed parts such connection can only be effected by carrying the thread through the point of intersection of the two gimbal-axes; any other (simple) connection would interfere with the free suspension of the instrument. The thread is then fixed to a crank-arm forming part of the vertical axis of a horizontal wooden disc which is mounted free to revolve outside the box (figs. 19 and 21). Above this disc is placed a horizontal shaft which carries a little wheel with a rubber edge bearing on the disc. By moving this rubber wheel nearer to or further from the centre, the ratio of its revolutions and those of the disc can be altered at will. Different gearings are marked, viz., from about 3 to 1, to 10 to 1, *i.e.*, *one* revo-

lution of the disc. It is the horizontal shaft, finally, which is directly connected with, and actuated by, the *propeller-fan* towed in the water. This fan consists of a simple piece of sheet-iron, cut in triangular shape, hitched to a rope at one corner and slit some way up from the opposite side, the loose flaps thus formed being curved into opposite directions after the style of a screw propeller. Those who are familiar with the working of the taffrail log and know how the least amount of bending of one of the blades to the extent of, say the thickness of a sheet of paper, produces immediate errors, may be somewhat surprised to hear of such a rough-and-ready contrivance being used with anything like satisfaction; yet this is a fact, for as it will be seen later on, the actual pitch of the fan is never taken for granted, but determined every now and then collectively with other factors to arrive at the scale. The fan has the advantage of costing next to nothing, and worked well down to the lowest speed. For higher speed a heavier propeller would be required, perhaps the same style that is used on steamers.

To follow up the *working of the instrument:* the propeller-fan causes its shaft to revolve, which in turn produces a slower rotation of the disc. Each revolution of this disc will pull up the lever below by means of the connecting thread, so as to revolve the worm-shaft to the extent of one tooth. Twelve pulls on the thread will thus cause one complete turn of this shaft and, through its worm-screw, advance the cog-wheel of the rough roll by one cog, so that the paper is advanced to a corresponding extent. Hence the

length of paper pulled through depends directly on the number of fan-revolutions and therefore represents distances. How the scale is found and adjusted will be explained later on. The paper is led over the thin guide-roller above, and the sharp bend thus obtained across the width of the paper is used as the place for recording. The magnet, already described, is balanced on a hard steel point, mounted on a vertical brass pillar which is made to slide up and down between certain limits. In its normal position a spring keeps it raised to the highest point (see fig. 21). Now the pivot is so placed that if it is lowered while the magnet rests on it, the edge of the latter will touch the bent surface of the paper. At the same time the remainder of the magnet rests on an inked pad, and being thus constantly kept inked, its edge leaves a mark wherever it touches the paper. The place where this mark is made, as we have seen, determines the position in azimuth of the instrument. In this particular instrument a mark half-way across the paper means due West for the boat's head; $\frac{1}{4}$ and $\frac{3}{4}$ width, North and South; while marks on either edge means East, for in that position both extremities of the magnet-spiral just touch the edges of the paper ribbon. A course curving round from N.E. to S.E., will therefore bring the marks to one edge of the paper and, as they disappear from that edge, cause them to reappear at once on the other. A circular course would be represented by a straight line slanting from one edge of the paper to the other. The lowering of the magnet's pivot is brought about by a cam, mounted on the centre of the worm-shaft, which causes a depression of the pillar for each revolution

of the said shaft, so as to cause the magnet's edge to touch the paper. A few more pulls of the lever frees the pillar again, which is then raised by its spring, allowing the magnet to rise clear of the paper and adjust itself in the meridian ; but as the worm-shaft also causes an advancing of the ribbon, each successive lowering of the magnet will find a slightly advanced part of the paper to mark upon. The record then consists of a series of dots on the ribbon which furnish the necessary data for plotting the chart. The periodical lowering of the magnet to touch the paper has another useful effect of "damping" its oscillations, the most violent swinging of the magnet being soon brought to rest.

ADJUSTING THE SCALE.

Having now got so far as to obtain lengths of ribbon to represent distances and marks on it to represent courses, there still remains the scale to be found, *i.e.*, what connection there is between miles of earth and inches of ribbon ; and the result to be plotted in chart form. As to the first, it is obvious that it is not only necessary to find or adjust a scale, but that there must also be some arrangement for keeping the scale constant so as to counteract the effect of tides and currents. It was not till some time after the completion of the instrument itself that this problem was solved in the following manner : taking one inch of paper as a unit, the number of revolutions of the outer disc required to move the paper by one inch can easily be found. This is an instrumental constant and happens to be 320 in the instrument described. Then assuming for convenience *ten* disc-revolutions

as an indicator for a simple normal scale, say one inch to the mile, it is required to find the distance over which the vessel has to pass during the course of ten disc-revolutions, in order that there shall be 320 revolutions (equal to one inch of paper) while the vessel proceeds over 1 mile of earth. This is clearly $\frac{1}{32}$ mile, or 165 feet. If we can now only know the interval of time during which 165 feet of ground are actually passed over, the scale can be immediately found from the number of disc-revolutions counted during that interval. If *ten* are counted, then the scale is 1 inch to the mile; if twenty, 2 inches, &c.; besides, by adjusting the rubber wheel on the disc, it is clear that the scale may be brought to any figure desired. For this purpose an optical range-finder is used, or more strictly, a "range-indicator," as it remains adjusted to a fixed range, 165 feet. Fig. 23 shows in diagram the simple device used, which is constructed on the principle of the sextant, only that a rigid bar, 3 feet in length, separates the two mirrors. The latter are so adjusted that, viewed through the telescope, any sharply defined object at a distance of 165 feet is seen as a single image, while at ranges exceeding or falling short of that distance, the image is doubled. In using this ranging device, it is necessary that the boat should pass as closely as possible by certain stationary objects, say an anchored boat, a buoy, fishing stake, or any object on shore, if near enough. When such occasion arises (at a time when it is thought advisable to check the scale) the telescope is fixed on the object, and from the moment when the images are seen to cover each other, the revolutions of the instrument's disc counted, leaving

off when the observer is abreast of the object. The number of these revolutions divided by *ten,* then gives the scale in inches to the mile at which the instrument was working at that moment; an adjustment to the

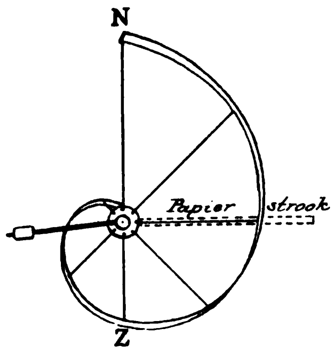

FIG. 22.

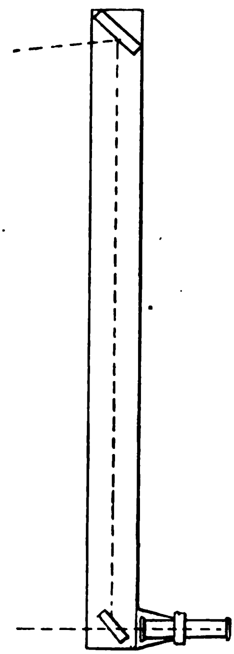

FIG. 23.

desired scale being always possible by means of the changeable gearing. If there is no current in the water any floating body may be observed. The scale can also be adjusted while *receding* from the stationary

object, though the former method is easier to perform single-handed.

It is hardly possible to imagine any more direct or accurate system for adjusting the scale. All that is required is a correct range-indicator, which can easily be tested now and then over the measured distance. The scale on which the hodograph is working can then be verified as often as one pleases, or may seem advisable by the circumstances under which the trip is made: changes in current, tides, influence of floating vegetation, &c. It is thus evident why the pitch of the fan has no influence on the results: *it is never taken for granted* any more than current or tide is, but re-determined at each range-taking, together with all other factors as a collective resultant governing the ratio between miles of ground and inches of paper.

Plotting the Results.

All that precedes would be of no practical use without some simple system of plotting the recorded result in chart-form. It would be far too tedious to have to measure the ribbon in inches and fractions and lay out all these courses on the paper in the directions indicated, especially in the case of sinuous creeks; therefore a method has been thought of to reproduce mechanically on the drawing-paper what takes place in the instrument. There it is the magnet which retains its orientation, no matter what the course of the vessel is, hence a disc of thin stiff substance—the "dummy compass"—is taken as representing the exact shape and size of the spiral magnet, and applied to the drawing-paper in such a manner that it can be moved

over any part of the paper and yet retain its orientation; which is accomplished by fixing it to a system of two parallelograms, the free side of which is pinned to the board in the required orientation (see fig. 24). The record-slip is then prepared for plotting by drawing a pencil line to connect all the dots made

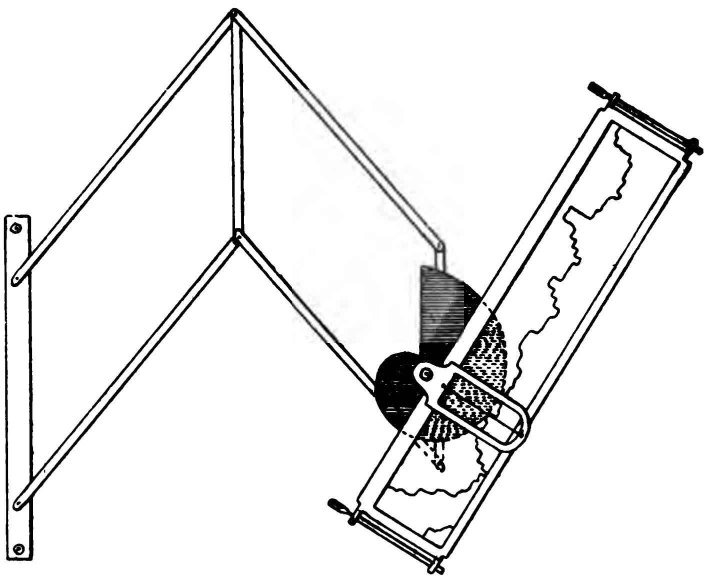

FIG. 24.

on it by the instrument and oiling or waxing the paper along the length of that line so as to make it transparent. It is then fixed in a carrier (fig. 24) with two rolls at the ends on which the paper is rolled or unrolled to bring successive portions of it into play,

a length of about 16 inches being always kept well stretched between the rollers. Along the length of this carrier is mounted to slide a light frame with a black thread stretching at right angles across the width of the record-slip in the carrier. At the foot of this frame, in a line with the thread is cut a circular aperture which fits over a raised collar on the dummy compass, its centre corresponding in place with the pivoting centre of the real compass. The frame carrying the black thread can therefore be fitted over this collar and turned round the centre, carrying with it the record-slip which, being stretched in the carrier, can slide with the latter lengthwise past the thread. The frame holds the carrier in such a position relative to the centre of the dummy, that the near edge is always kept at a distance from it equal to the distance from the magnet's pivot which it took up in the instrument. Thus we have on the drawing-board a complete imitation of what happens in the instrument :—the edge of the dummy represents the marking edge of the magnet and the black thread, radiating, as it does, from the centre of the dummy, shows the line across the paper at which it was bent over the guide-roll in the instrument at the moment when the mark on the paper—now indicated by the place where the thread cuts the record-line—was made by the magnet. The sliding of the carrier with the record past the thread repeats the progressive motion of the paper in the instrument. All that remains to be done then is to imitate on the drawing-paper the actual motion of the vessel in the correct directions. To effect this, the beginning of the record-line is brought under the black thread and the place of its intersection with the

thread noted, this being the place at which the magnet made its first mark. But since the magnet always remained oriented to the meridian it must have been the position in azimuth of the remaining parts which caused the mark to fall on that particular spot. The carrier is therefore revolved round the central pivot until it takes up a position in which the dark edge of the dummy, visible through the semi-transparent paper, is seen to coincide with the point of the thread cut by the record-line. As soon as that is the case, the straight edge of the carrier points in the direction of the vessel's head at the start. The carrier is then pressed against the drawing-paper and the dummy slid along its edge, thus imitating the vessel's own motion ; but as the centre of the dummy is furnished with a pencil point pressing lightly against the paper, this motion will cause a line to be drawn into the given direction. Supposing the vessel to have kept on the given course for some time, a record-line will have been marked out parallel to the edge of the paper; hence as the dummy slides along, carrying the black thread with it, the place of intersection with the dummy-edge will not be affected by such parallel motion. The instant, however, at which the record-line moves off that edge it means that the vessel has changed her course. The dummy is then stopped and pressed to the paper in its turn while the carrier is revolved into a new position, corresponding to the new course, in which the required coincidence is again obtained, and so on till the end of the record, when the pencil shall have traced on the paper a complete facsimile of the route originally followed.

Noting Details along the Route.

It is perhaps somewhat misleading to call the hodograph an automatic instrument. As a device for recording the elements of a "dead reckoning" pure and simple, it is indeed automatic, provided there is no change in current, leeway, &c., but for the purpose of mapping out a creek or river, it is evident that someone is required to watch it to a certain extent for keeping note of the various features of the route, villages, bridges, affluents, width of creek, soundings, &c. This is done by marking on the record-slip below the magnet the time at which such points are passed, and entering that time with the necessary description in a note-book kept handy. The various marks thus made on the record-slip serve to locate the exact corresponding spots on the map, when the plotted line is to be worked out later on with the aid of the field-notes. Besides doing this, the person on watch has to verify the scale occasionally, counteract the leeway, which may be occasioned through tracking or sailing, by adjusting the axis of the instrument (not necessarily parallel to the keel of the vessel) to point into the direction of the creek or the line in which the boat is actually travelling, and various minor points to be attended to occasionally, all of which, however, can easily be performed by a single observer throughout the day. At night, if left to itself, the hodograph will continue to work, subject to such of the above disturbing agencies as may then react upon its results. The plain record obtained in this manner has its use for comparative purposes.

Place in Vessel.

The place to be occupied by the instrument depends entirely on the kind of craft on which it is to be used. In the author's house-boat[1] it was placed inside the cabin close to the vessel's side, forward, while connected with the revolving fan by means of a thin brass shaft enclosed in a tube leading aft slantwise through the vessel's side, about two feet above the water-line. At the end of this shaft an ordinary one-inch rope was hitched which dragged the propeller through the water somewhere abreast of the rudder-post, where an eye could be kept on it for entangled weeds, &c. Though weeds were a terrible nuisance in the beginning, it was found that by passing the rope through a ring outrigged a few feet in front of the fan, slightly above the water-line, an almost total immunity was secured from floating vegetation. This outrigger also prevents the fan from being sucked into the eddies of the vessel's wake. The extra friction of the shaft seemed to have little effect, since even at the low speed of one mile an hour or less, the fan kept working. To transmit the revolutions of the shaft, coming at an angle through the side of the boat, to the horizontal upper shaft of the instrument, the author used a coiled cylindrical spring, which will transmit with practically no friction every revolution from one shaft to another at any angle, fixed or variable, up to 90 degrees or

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[1] A craft much used in China, and existing in all sizes and styles; usually adapted for propulsion by sailing, towing, tracking, poling or "yulowing," *i.e.*, sculling with one or more heavy stern sweeps, manned by native coolies.

more. Such flexible joint is also needed to allow of lee-way corrections.

Another kind of vessel on which the hodograph has been used with success over many a mile, was a light canoe, worked with a double-bladed paddle. The instrument fitted into a square socket immediately behind the well, projecting a few inches above the deck. A smaller propeller-fan was hitched to the rope, and allowed to drag a foot or so behind the (rudderless) stern-post. The instrument worked very well in this manner, keeping faithful record of all the little craft's lonely wanderings. As a rule the canoe was used for the shorter side-trips, exploring smaller creeks and cut-offs, with the house-boat as a temporary base. Her main use, has, however, been in circumnavigating the great number of lakes on the second map mentioned in the footnote on page 65, where she could follow the shore into every little bay and inlet too shallow for other boats. As in this case the record-slip was not accessible for marking times, &c., a rough sketch of the route followed was kept in a field book lying on the deck in front of the observer, with the aid of which the instrumental traverse could afterwards be filled out with the necessary details, the configuration of the route itself affording sufficient means of identifying the various points affected. A more efficient and self-contained "outfit" for exploring and mapping small creeks and lakes could hardly be imagined. The swift, arrow-like craft was little affected by current or side-wind, gliding in a few seconds by shallow and swampy places, the mapping of which by ordinary means might have occupied a day. Fig. 26 shows the two boats which have proved

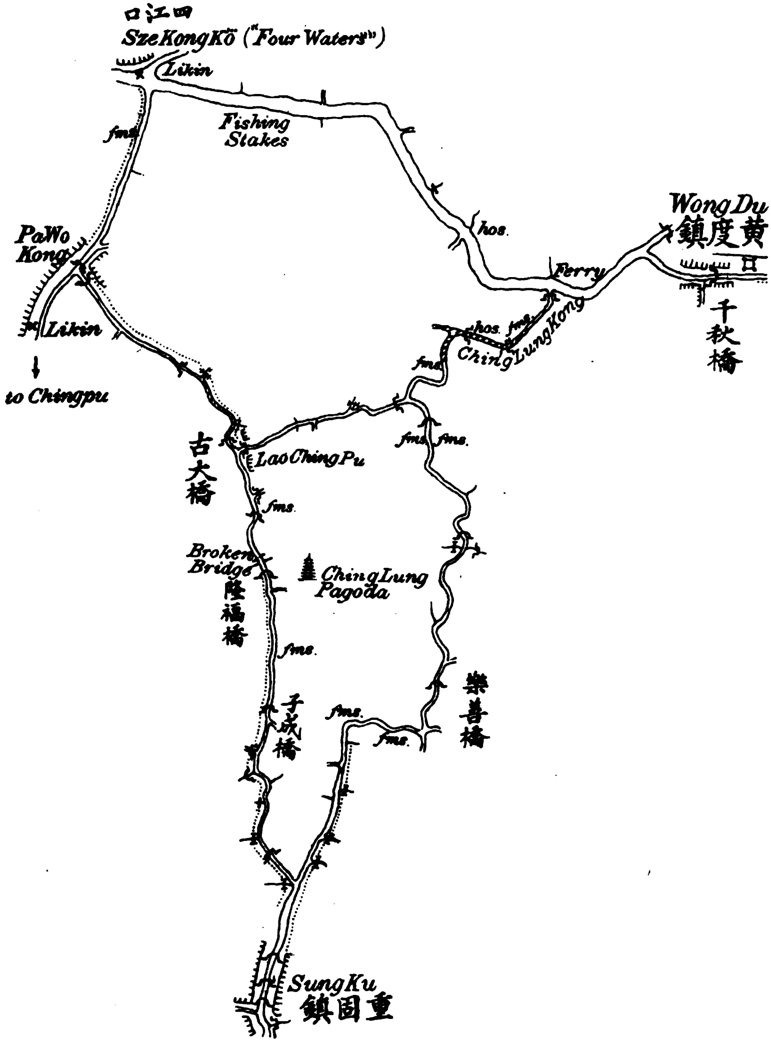
口江四
Sze Kong Kō ("Four Waters")
Likin
Fishing Stakes
fms.
Wong Du
鎮度黄
hos.
Ferry
千秋橋
Pa Wo Kong
Likin
to Chingpu
hos.
Ching Lung Kong
古大橋
Lao Ching Pu
Broken Bridge
隆福橋
Ching Lung Pagoda
子成橋
樂善橋
Sung Ku
鎮固重

FIG. 25.

themselves suitable for the work mentioned in the foregoing pages. The black line slanting aft from below the front window in the house-boat is the tube containing the propeller shaft.

ACTUAL RESULTS OBTAINED.

In accuracy of results the hodograph cannot be compared with the two instruments which are described in the earlier chapters. Apart from ques-

FIG. 26.

tions of current, leeway, unequal slip of propeller, &c., which must necessarily render all "dead reckoning" on water less reliable than "traversing" on terra firma, the indirect manner in which its final results are obtained offer many openings for errors and slips. A minute analysis of all the links in the chain leading from the trip itself to its final counterpart on paper would be a long business; in the pedograph—

an instrument of later date—the author has succeeded in reducing the number of these links to *eight*, while in the cyclograph the entire conversion from terrane to paper comprises but *three* positive steps.

A specimen of a creek survey worked up from hodograph data is given in fig. 25. Almost every creek on the maps mentioned was traversed twice, in opposite directions, and the results compared and adjusted where necessary. In this manner the probable errors were kept within reasonable limits, and final results obtained which, tied and checked whereever possible by independent bearings, answered every purpose of the use and requirements already gone into at some length.

APPENDIX.

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